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PREDGOVOR

Opći trend razvoja i prestrukturiranja proizvodnje u tehnološki razvijenom svijetu sve se više zasniva na modernizaciji i reinženjeringu, čiji je temelj primjena novih tehnologija, fleksibilne automatizacije i organizacije, kompjuterski integrirane proizvodnje s osnovnim ciljem da se proizvodi kvalitetnije, jeftinije i brže. Na tragu tih spoznaja Naučno nastavno vijeće Mašinskog fakulteta Univerziteta u Bihaću odlučilo je da svake druge godine organizira međunarodni skup pod nazivom ***" Revitalizacija i modernizacija proizvodnje"***. Prvi skup RIM '97 organiziran je s ciljem sagledavanja i analize stanja u industriji nakon rata i stvaranja osnovnih pretpostavki za širu primjenu revitalizacije i modernizacije proizvodnje.

Međunarodni skupovi RIM održavaju se pod motom:

- Industrijska proizvodnja se realizira uz stalne i intenzivne promjene koje se sastoje u prilagođavanju novim okolnostima i zahtjevima tržišta.
- Konkurentnost i promjena strukture proizvodnje, orijentacija prema tržištu, reinžinjering i revitalizacija poslovnih i proizvodnih procesa i sistema su imperativ opstanka poduzeća.
- Revitalizacija i reinženjering proizvodnje su procesi neprekidnog inoviranja i unapređenja postojećih proizvoda, tehnologija, proizvodnih procesa i sistema od čije efikasnosti primjene ovisi opstanak proizvodno-poslovnih sistema.
- Usvajanje koncepta industrije 4.0.

Ovogodišnja petnaesta konferencija RIM 2025 održava se pod nazivom "Razvoj i modernizacija proizvodnje" sa tematskim područjima:

A. Mašinsko inženjerstvo
B. Dizajn i tehnologija drveta
C. Elektrotehnika i računarstvo
D. Tehnologije i konstrukcije u građevinarstvu
E. Dizajn i tehnologije tekstila
F. Pravno-ekonomska regulativa i standardizacija
G. Osiguranje kvaliteta, zaštita okoliša i održivi razvoj

Na konferenciji sudjeluje 328 autora i koautora iz zemlje i inozemstva sa 180 radova. Očekuje se da će ovaj skup i prikazani radovi biti novi konkretni podsticaj i doprinos u transferu znanja i tehnologija i razvoju moderne proizvodnje, te da će ponuditi odgovore na niz pitanja kako usavršiti proizvodnju i poslovne sisteme učiniti profitabilnijim i efikasnijim na turbulentnom međunarodnom tržištu.

Svim autorima radova, suorganizatorima, pokroviteljima, institucijama i svim drugima koji su pridonijeli održavanju ove Konferencije, organizator najtoplije zahvaljuje.

Dekan Tehničkog fakulteta

Prof. dr. Damir Hodžić

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Prof. dr. Fatka Kulenović

PREFACE

The general trend of development and restructuring of the manufacturing in the technologically developed world is increasingly based on modernization and reengineering, based on the application of new technologies, flexible automation and organization, computer-integrated manufacturing with the basic goal of producing better, cheaper and faster. Following these findings, the Scientific Teaching Council of the Faculty of Mechanical Engineering, University of Bihac decided to organize an international conference every second year called "Revitalization and modernization of the manufacturing". The first conference of RIM '97 was organized with the aim of reviewing and analyzing the situation in industry after the war and creating the basic preconditions for the wider application of revitalization and modernization of the manufacturing.

RIM International Conferences have been held with the motto:

- Industrial manufacturing has been realized with constant and intensive changes that consist of adapting to new circumstances and market requirements.
- Competitiveness and change of the manufacturing structure, market orientation, reengineering and revitalization of business and manufacturing processes and systems are imperative for the survival of the company.
- Revitalization and reengineering of the manufacturing are processes of continuous innovation and improvement of existing products, technologies, manufacturing processes and systems on the efficiency of which the survival of the manufacturing and business systems depends.
- Application of the concept of industry 4.0.

This year's fifteenth conference RIM 2025 is held under the title "Development and modernization of the manufacturing" with the following thematic areas:

A. Mechanical Engineering
B. Wood Design and Technologies
C. Electrical Engineering and Computer Science
D. Technologies and Structures in Civil Engineering
E. Textile Design and Technologies
F. Law-Economics regulations and standardization
G. Quality Assurance, Environment Protection and Sustainable Development

The conference is attended by 328 authors and co-authors from the country and abroad with 180 papers. It is expected that this set and presented papers will be a new concrete stimulus and contribution in the transfer of knowledge and technologies, development of the modern manufacturing and that it will offer answers to questions on how to improve the manufacturing making business systems more profitable and efficient in turbulent international market.

The organizer would like to thank all the authors, co-organizers, sponsors, institutions and all others who contributed to the organization of the Conference.

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President of the Organisation Committee

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Generalni pokrovitelj konferencije RIM 2025

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A

Artificial Intelligence and Additive Manufacturing. The Future of Product Design, Development and Manufacturing

Adis J. Muminović[1*]

[1] Department of Mechanical Design, University of Sarajevo – Faculty of Mechanical Engineering, Sarajevo, Bosnia and Herzegovina

[*]E-mail: adis.muminovic@mef.unsa.ba

Abstract. This paper provides an overview of the possibilities of using artificial intelligence (AI) in the field of product development and design. Special focus is placed on analysing the possibilities of using so-called "text to 3D model" applications for creating computer aided design (CAD) models of a new products. The analysis was conducted on a real case study example of the development and design of a stool chair. 3D models created using AI were fabricated using additive manufacturing (AM) technologies into a fully functional product. To produce this chair total work time of a single working man (engineer) was only 1-hour work using computer, everything else was done using machines (computer and 3D printer). Total human working time has been reduced by an incredible 99% using AI and AM compared to conventional CAD modelling and conventional manufacturing methods.

1. Introduction

Artificial intelligence is slowly becoming an indispensable tool in many fields. Currently, it has found special application in the fields of generating answers to simple questions and in the fields of generating textual documents and other digital products in areas such as graphic design, web page design, presentation, etc. Also, it has become an irreplaceable tool in the field of image generation. In addition, it slowly starting to be used in the field of video material generation as well.

In the case of mechanical and manufacturing industry, application of AI is not a new thing, it was used already in many fields of mechanical engineering. In the field of product development and design process it was often used to try to replace human based knowledge experience with AI based decision. This is emphasized in the paper [1] where the authors states that using AI to gather the experience and know-how that to date has been considered the preserve of humans and put it to work in ICT opens the way to the use of AI in product design. Extensive research on the use of Big Data and AI in the field of product design was conducted in the paper [2]. Authors claim that traditional product design methods fall short due to their strong subjectivity, lack of real-time data, limited survey scope and poor visual display. The most important goal of paper [2] was to show how different types of collected data can be used in product development and design process. Big data in the product lifecycle contains valuable information, such as customer preferences, product evaluation, market demands and visual display. Product images contain shape, colour and texture information that can inspire designers to quickly generate initial design schemes or even new product images. This is one of the first papers which mention how AI generated images can be used for the inspiration of new products. Paper [2] provides a comprehensive review of big data and AI-driven product design, focusing on how big data of various modalities can be processed, analysed, and exploited to aid product design using AI algorithms. It identifies the limitations of traditional product design methods and shows how textual, image, audio, and video data in product design cycles can be utilized to achieve much more intelligent product design. Regarding the product design process, most authors agree that the most important thing is the collaboration between designers and AI, not just the full use of AI [3]. Paper [3] is one of the most recent papers which explain the potential for human-AI design collaboration, which increases understanding of the role of artificial intelligence (AI) in the design process. This paper tries to answer to the question “How does AI currently support the design process and how could it do so in the future?”. Result of the research presented in [3] is that AI agents can potentially assist designers by

providing inspirations, defining design problems with constraints, offering grounded metaphors, and exploring design materials. Connection between design innovation and AI generated content is explored in paper [4]. This study explores the role of AI-generated content (AIGC) technologies and how they will drive design innovation. Also, the paper identifies promising future applications of AIGC technologies. It delves into the vision, challenges, and opportunities presented by AIGC technologies, offering insights to inspire further research agenda. In this paper, it is stated that by leveraging various AIGC technologies, designers can unlock new avenues for creativity and productivity, ultimately shaping the future of design innovation. From the above mentioned papers, it can be seen that AI in the field of product development and design has so far been mostly used for processing data related to the product development and design process and for generating ideas and concepts in the initial stages of design. However, no works can be found that address the area of generating final usable physical products generated entirely (not just as an aid) with the help of AI.

Regarding additive manufacturing (AM) and AI, the most of the recent research is currently related to the application of AI in the field of production parameter optimization in various AM technologies and in the field of using AI for AM process control [5, 6,]. Paper [7] explores the integration of AI, machine learning (ML), and deep learning (DL) techniques to improve and innovate in the field of AM. It is stated that AI-driven design optimization procedures offer innovative solutions for the AM of complex geometries and lightweight structures. By leveraging machine learning (ML) algorithms, these procedures analyse extensive data from previous manufacturing processes to enhance efficiency and productivity. Also, a lot of research is based on the development of so-called lattice structures and materials inspired by bio-structures. Such structures together with topological optimizations can offer significant advantages compared to standard products designed as products from solid materials [8, 9]. Such materials achieve significant advantages over conventional forms of design and manufacturing. The advantages are primarily reflected in the reduction of product weight while maintaining the same or similar stress state. In paper [10] it is stated that generative AI techniques, including generative adversarial networks (GAN), genetic algorithms, and large language models (LLMs), offer efficient solutions for optimizing material properties, reducing manufacturing costs, and accelerating the development timelines. This paper is specifically focused on the field of use of AI for design and development of nature and biological inspired materials.

Regarding computer aided design (CAD) 3D modelling and general 3D model creation using artificial intelligence, this field is in its infancy. All AI models which are currently developed, create 3D models based on a text query or based on a picture as a reference. There are several commercially available websites, but they are all based on generating simple 3D models. First paper which basically open up this field is paper by the authors from Google [11]. In this paper they presents their system DreamFusion. It is text-to-3D using 2D Diffusion system. One of the best papers that provides a general overview of AI methods and technologies for "text to 3D" generation of 3D models is the paper [12]. This paper present different AI technologies which exist today. Also, this paper presents places of usage of text-to-3D technology in various applications, including avatar generation, texture generation, scene generation and 3D editing, but it lacks mentioning possibilities of usage these technologies in engineering fields for creation of precise CAD 3D models. Paper [13] presents two systems for text to 3D model AI generator Dreamfusion and Magic3D. This paper shows very well that AI is not just chatGPT, AI is much more than that. Authors in paper [14] propose a novel method that generates high-quality and diverse 3D models from text prompts in a feed-forward manner.

In the near future, the development of an increasing number of new technologies and methods for generating 3D models based on textual or other queries is expected. Currently, it can be seen that the focus is on creating 3D models that primarily find use in the areas of generating 3D models for video games, virtual reality and augmented reality. Although this is not their primary focus, above mentioned AI technologies open up completely new possibilities in the field of product development and design. Especially in the field of design of products which are more design and user-oriented, products where design and function are ahead of precision and engineering, such as, for example, products from the furniture industry, like chairs. This is especially evident when AI technologies and 3D models generated using these technologies are combined with additive manufacturing (AM) with the goal of automatic

manufacturing of generated 3D models. The time that a person has to spend to get from the initial idea for a new product to a functional product is drastically reduced by the combination of these two technologies compared to conventional technologies for 3D modelling (CAD modelling using software's like SolidWorks) and conventional manufacturing methods like injection moulding.

In this paper, we have shown, through a case study of the design and manufacturing of a stool chair, how much impact the combination of AI and AM will have on the product development and design process in the future.

2. Stool chair design using AI

The first commercial systems for generating 3D models from text or picture appeared this year. Although this is the beginning of such technologies, the systems are already usable for generating 3D models of animals, plants, fruits, vegetables, etc. These are 3D models that can be used for various purposes such as video games, animations, virtual reality, augmented reality, etc. Although such systems are not intended for generating engineering 3D models (CAD models), they can be used for generating products that are more user and design oriented or products where high precision is not required. Products from furniture industry are one of the best examples of user and design oriented products. In this research stool chair is chosen as a case study. Stool chair is chosen because it is a relatively small product that can be manufactured as a fully functional product using currently available AM devices. One of the currently most popular 3D model generator is web system Meshy AI (https://www.meshy.ai/). This system is used in this research. Meshy AI can create 3D models from text prompt or using image as a reference. In first step several stool chairs are designed using different text inputs. For every text input system gives four designs. Figure 1 shows designed stool chairs for four different text inputs.

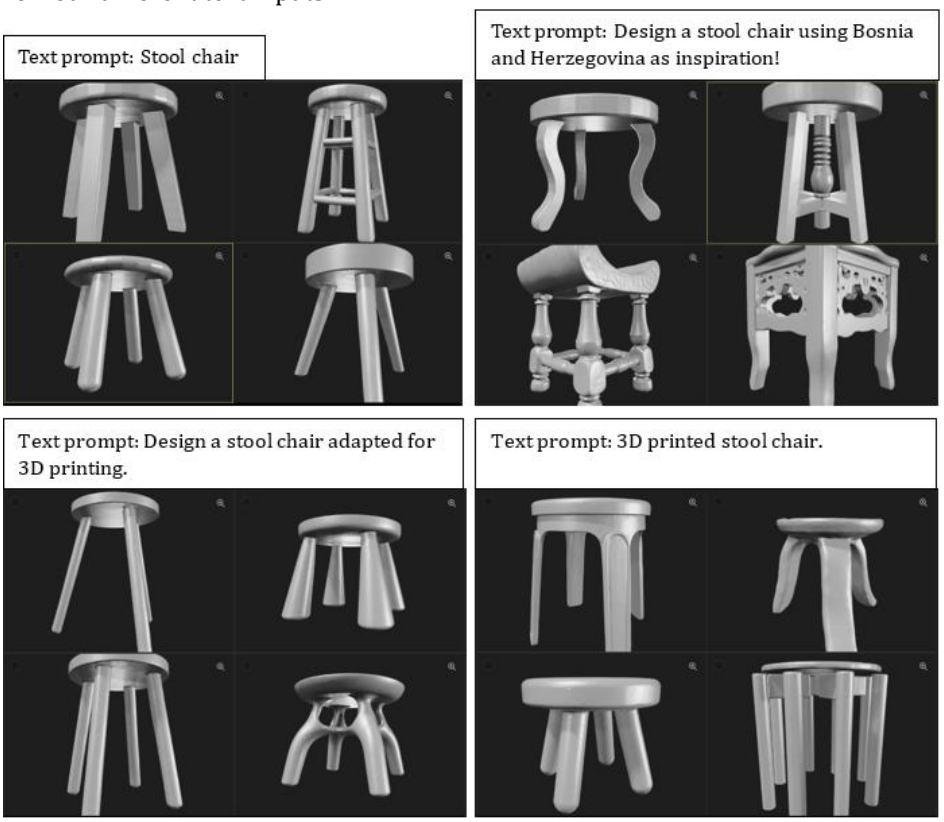

Figure 1. Results of AI generated 3D models of stool chairs using Meshy AI for different text prompt.

From Figure 1, it can be seen that the AI system is not yet optimized to fully "understand" the concepts that are required of it. It can be seen that the system did not generate 3D models adapted for 3D printing in every variant (design without supports, with less amount of material used, etc.). However, when the system

was asked to design a chair inspired by Bosnia and Herzegovina, it can be seen that the designs of all four chairs contain oriental elements of Bosnian and Herzegovinian culture.

Another way to generate 3D models using Meshy Ai is by using an image as a reference. In this case, images of chairs generated by ChatGPT based on a text prompt were used. ChatGPT generates much better images of chairs based on a text prompts. The generated images were then used as an input into Meshy AI as a reference for generating the 3D model (Figure 2). Figure 2 shows that chatGPT "understands" concepts such as 3D printing or cultural ornaments of Bosnia and Herzegovina significantly better, however, on the other hand Meshy AI does not generate a sufficiently detailed 3D model with all the details visible in the image. 3D models generated for stool chair adjusted for 3D printing are quite accurate, but 3D models generated for a stool chair designed using Bosnia and Herzegovina as an inspiration lack fine details.

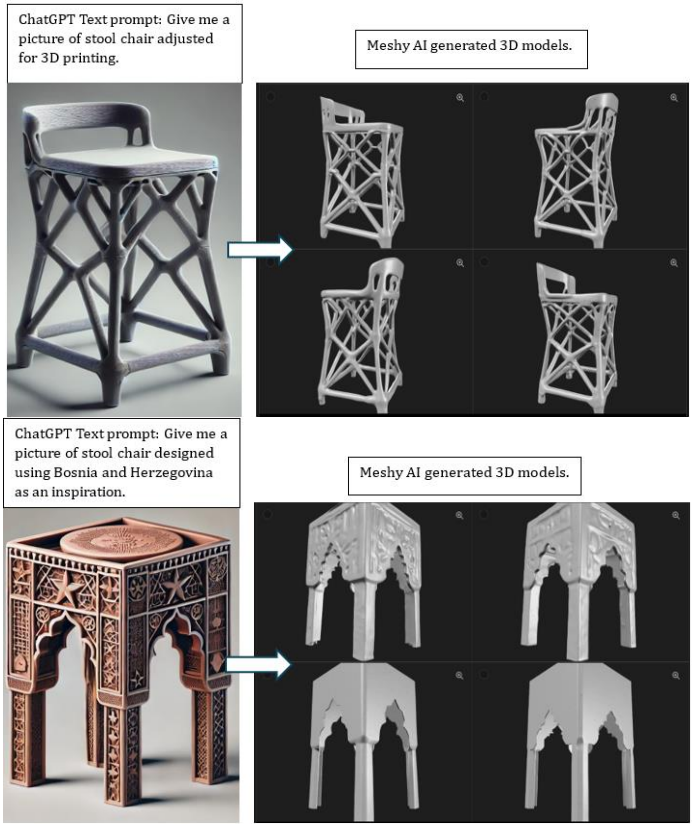

Figure 2. Results of AI generated 3D models of stool chairs using Meshy AI for different image references generated by ChatGPT

Generating all of these chairs took significantly less time (only few minutes) than it would have taken to manually 3D model all of these variants in some of the CAD modelling software's. Analysing generated designs from the field of optimization for manufacturing using AM (printability), the chair shown in Figure 3 was selected for further manufacturing.

Figure 3. AI generated stool chair chosen for manufacturing using AM.

This chair can be considered relatively well optimized for AM manufacturing, primarily because it does not need much support structures during manufacturing. It will be produced in upside down position. Also, this design of stool chair is a good example that such AI systems for generating 3D models should have the ability to further edit the model through text queries. In this specific case, the 3D model of the chair could be further optimized for AM technologies by levelling the upper surface of the chair (seat). It should be possible to further edit the 3D model through a text query such as: "Make the upper surface of the seat to be flat".

3. Additive manufacturing of a stool chair

AM enables that manufacturing of products can be almost fully automated with minimal need for human labour. The tasks that must be performed by a person are maintenance of the device, replacement of materials, removal of finished products from the device, etc. However, many of these jobs can also be further automated using other machines for automation of manufacturing, such as, for example, robots. In the case of AM, total human working time is around 1% in the total time of the product manufacturing. Also, one worker can maintain production on significant amount of machines in the same time. In the case of regular 3D printers, it is estimated that one worker can work with up to the 30 devices in the same time. In the case of print farms, it is estimated that 500 devices can be operated by 15 workers. In the case of fully automated print farms it is estimated that one worker can operate more than 100 devices [15, 16]. Much research has been conducted in the field of integrating AM into manufacturing processes and their impact on the human workforce [17-20].

In the case of this research, Fused Deposition modelling (FDM) AM technology was used. Rase3D Pro2Plus AM machine (3D printer) was used. This printer is selected because it has large build volume 305×305×605 mm, which is needed to manufacture AI generated stool chair from Figure 3. First step was to prepare generated 3D model for AM. This is done in IdeaMaker software. The fastest profile with 0.25 mm height was selected. Infill density was 20%. Other AM parameters are left as default for Speed profile and PLA (Polylactic acid) material. PLA material is selected because it is “easy to print” 3D printing material with good mechanical properties. 3D printing time in this case was around 60 hours. The printing time is this big because this is regular Raise3D Pro2 Plus printer. It is important to notice that upgrade kit can be booth for this printer which can increase printing time up to 5 times, so the printing of this chair will be around 10 hours. Also, other AM technologies, with higher print layer, are available which can reduce the printing time up to only several hours, for example 3D printing head mounted on robot arm with print layer height of 1mm. Prepared AM generated stool char for AM is shown at figure 4.

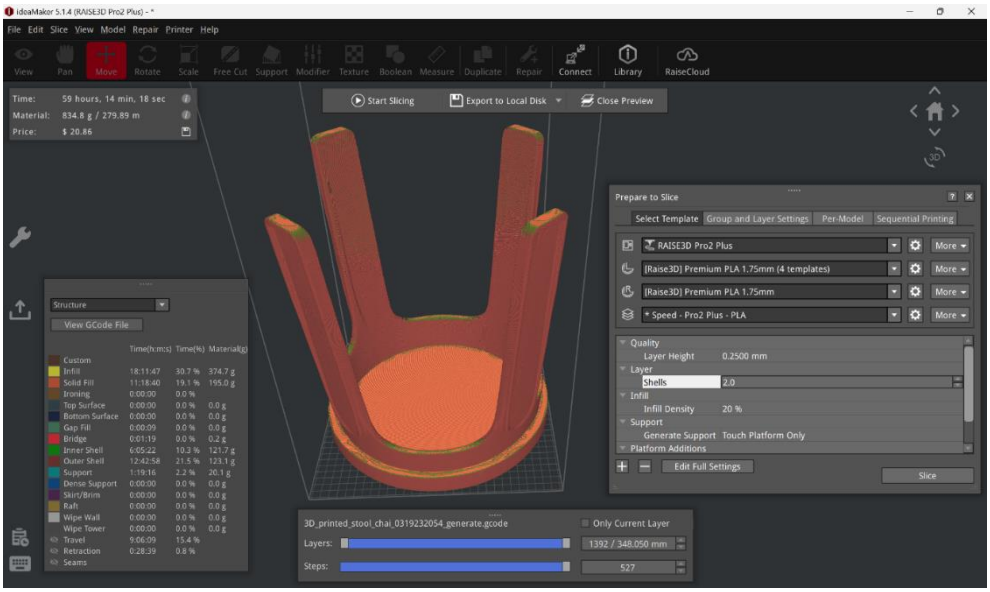

Figure 4. AI generated stool chair prepared for AM.

Regarding mechanical properties of the stool char 3D printing parameters are selected taking in consideration author experience in the field of AM. Goal was to select parameters which will give the best relation between mechanical properties and the speed of 3D printing. Future optimization of 3D printing parameters are possible using more advance testing of mechanical properties of the chair. It will be necessary to 3D print more chairs with different parameters and make a mechanical test. Stool chair at the end of the manufacturing process is shown at figure 5. On the left side the chair is shown inside the 3D printer and on the right side it is shown on the table. It is important to notice that this is fully functional chair which can be used on regular basis as it is shown at figure 6. Figure 6 shows a male with approximately 70kg of weight using the chair.

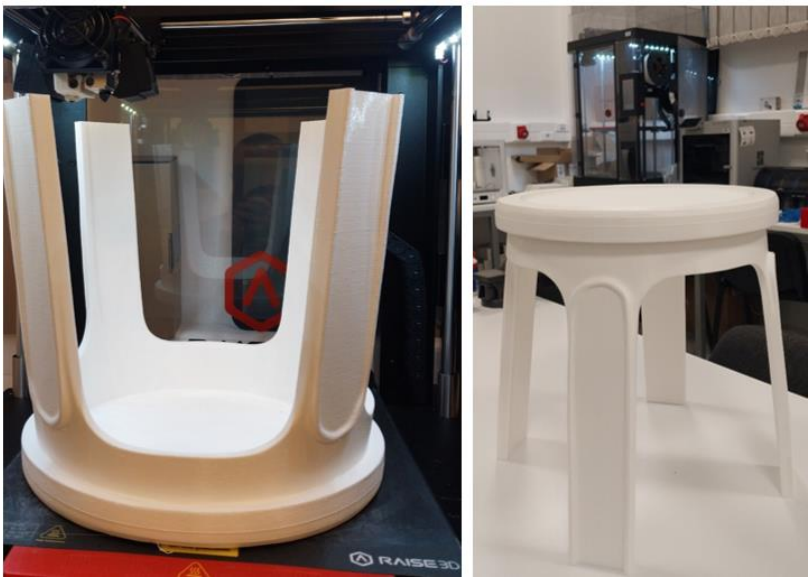

Figure 5. AI generated stool chair after the manufacturing using AM.

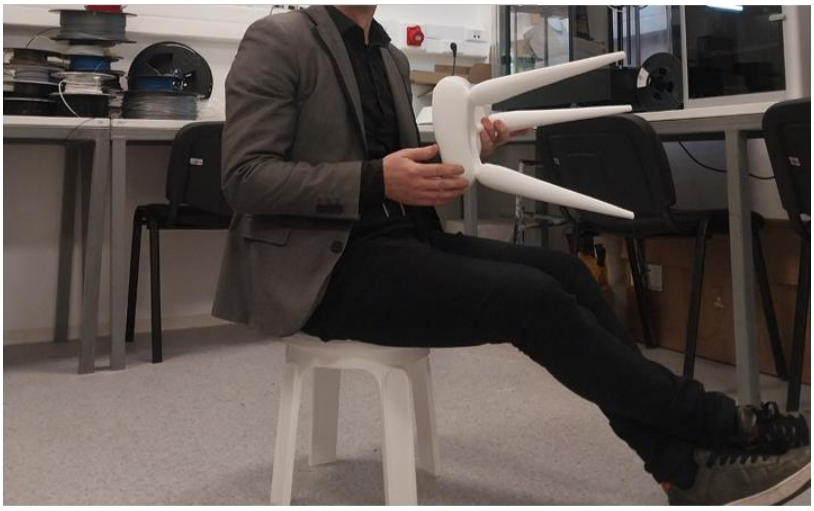

Figure 6. AI generated and AM manufactured stool chair in regular use.

4. Human working time analysis

The most important advantages of usage of AI and AM in product development, design and manufacturing is a reduction of human labor working time which needs to be done to produce one chair and the reduction of expanses needed to produce one chair, or small amount of chairs. In this case, production of only one chair is taken for comparison. Table 1. shows comparison of working time needed in the case that the same chair, shown at figure 3, needs to be designed, developed and manufactured using traditional design and development methods and traditional manufacturing technology on the one side and the combination of AI and AM on another side. Injection moulding technology is selected as a representative of traditional technology because it is a "plastic" stool chair and in the case of traditional technology it will be manufactured, most probably, using injection moulding.

Table 1. Comparison of human working time needed to produce one stool chair shown at figure 3 using traditional design and development methods and traditional manufacturing technology on the one side and the combination of AI and AM on another side.

Activity	Traditional methods Time [h]	AI and AM Time [h]
Concept design and evaluation phase	4	≈ 0
CAD 3D modelling	3	≈ 0
Preparation of technical documentation	3	≈ 0
Complete development of the tool for injection moulding	200	≈ 0
Preparation of 3D model for manufacturing (slicing)	≈ 0	≈0.5
Preparation of machines for manufacturing	8	≈0.5
Total:	218	1

From Table 1 It can be seen that total amount of human working time in the case that traditional design and development methods and traditional manufacturing technology was used is 218 hours. On another side, in the case that AI and AM combination was used total human working time is only around 1 hour,

which is less than 1% of the time. It is important to notice that this is the case of the one chair manufacturing. In the case that massive production is needed and if speed of the manufacturing is important factor than separate analysis needs to be done. Selected number of injecting moulding machines needs to be compared with, for example, 100 AM machines (3D printers). Several injection moulding machines can produce massive amount of chairs in small amount of time, but that requires more human labour and expensive manufacturing facility. One injection moulding machine requires minimum one man to operate the machine, on the another hand, as early mentioned, one man can operate with 100 3D printers in the case of fully automated 3D print farm. Cost effective analysis will be done in future papers by the same author.

4. Conclusion

Artificial intelligence and additive manufacturing are certainly two technologies that will fundamentally change the way how product development, design and manufacturing are carried out in the future. As can be seen from this paper, they will have a special impact on the creative and digital part of the product development and design process. AI can very easily and quickly generate a large number of potential solutions for the design of a new product. Also, AI will soon be able to very quickly generate 3D models of designed products. Especially in cases where products are more design oriented and user-oriented, like chairs for example. Designed products will be able to be manufactured with the help of AM without the need for human labor or with minimal need for human involvement. The mentioned technologies are in their initial development cycle, so their full application requires additional time, which will certainly occur in the future. In terms of engineering applications, it is expected that a system for generating 3D models will be developed that allows for additional editing of the model after its initial generation via a text query. This primarily refers to editing the model in terms of incorporating the experience and knowledge of the engineer into the design of a new product. The engineer can determine, using personal experience and knowlage, whether the product is well designed in terms of stress analysis, stability or design for manufacturing. It must be possible to further edit the designed product with additional queries in order to achieve some of the above mentioned criterias.

It can be concluded that the use of AI technology will become an integral part of the product development and design process. AM technologies will also become an integral part of the manufacturing processes in the future, but not yet in cases of mass production, although AM devices are rapidly advancing and the speed of manufacturing is rapidly increasing. Additional research and analysis of the possibilities of whether print farms can replace traditional manufacturing processes are needed. On the other hand, AM devices will enable a higher level of individual production and further decentralization of production from large industrial centers to small decentralized manufacturers.

Both technologies will lead to a reduced need for ordinary labor (ordinary machine operators), while on the other hand, the need for small number but a highly skilled workforce that is familiar with AI and AM systems and at the same time has engineering knowledge will increase.

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Monte Carlo Simulation of Assembly Method of Group Interchangeability

Sanel Gredelj

Faculty of Technical Engineering, University of Bihać, Bosnia and Herzegovina

E-mail addreses: sanel.gredelj@unbi.ba

Abstract. Group interchangeability is one of the methods of dimensional analysis which is applicable in the assembly process. This method is applicable in mass and large-scale production with small groups of assembly tolerances. The design values of the tolerances of the assembly parts are wide economically viable manufacturing tolerances. After manufacturing, the parts are sorted according to their actual dimensions into groups within the manufacturing tolerance and are assembled into the corresponding groups of tight assembly tolerances using the method of complete interchangeability. This is where the problem of assembly scrap arises, which relates to parts that do not have a corresponding part with which they can be paired or assembled, because within a group there are more of some parts than others. One of the solutions to this problem is the application of Monte Carlo simulation methods. It is assumed that the tolerance dimensions of the parts are distributed according to a normal and uniform distribution. The Monte Carlo method is a probabilistic method based on performing numerous fictive experiments using random numbers and requires the use of a computer because a large number of random numbers and variables need to be generated. This paper presents a simple and reliable Monte Carlo simulation procedure implemented in Microsoft Excel, demonstrated through a specific numerical example involving two different types of fits. The procedure can be applied in real production.

1. Introduction

The technological assembly process is the second basic type of production, where components are joined together using permanent or semi-permanent techniques. Assembly is more than putting parts together and brings together and encompasses all the upstream processes of design, engineering, manufacturing, and logistics to create a complex technical system that performs a function [1,2].

Dimensional analysis of assembly is a set of calculations and analytical procedures conducted in the development and analysis of assembly and technological methods of machining. Dimensional analysis ensures the correct ratio of interrelated dimensions and determines permissible tolerances. The need for interchangeable parts and the need for parts that will fit without rework or adjustment at assembly can only be ensured by dimensional analysis. This factor is a hallmark of modern manufacturing philosophies [3,4].

Dimensional analysis aimed at ensuring the required accuracy of resulting dimensions can be economically solved by one of the following five methods: complete (full) interchangeability, maximum-minimum method, incomplete interchangeability, group interchangeability, and fitting or adjustment [2,3,5].

In this paper the method of group interchangeability was analyzed with the application of Monte Carlo simulation.

The topic of Monte Carlo Simulation of the Assembly Method of Group Interchangeability represents a niche area within tolerance analysis and assembly process optimization. However, there is currently a lack of literature that directly addresses this specific combination, namely, the application of Monte Carlo simulation to the method of group interchangeability. Despite this, there are studies that explore key components relevant to the topic. In paper [6] was conducted a tolerance analysis of mechanical assemblies using Monte Carlo simulation. The paper demonstrates how statistical methods can be applied to evaluate the impact of dimensional variations on assembly performance, providing a foundational understanding that could be extended to group interchangeability scenarios. Similarly, in paper [7] was focused on tolerance allocation using Monte Carlo simulation. This approach aims to optimize manufacturing tolerances to improve assembly efficiency and reduce costs, which is also relevant to group

interchangeability, where components are classified into groups based on dimensional characteristics. Although neither study directly addresses group interchangeability, both provide methodological frameworks and tools that can be adapted and applied in future research on this specific topic.

2. Cost and tolerance optimization and DFMA

Permissible tolerances have an influence on manufacturing and assembly costs differently. Wide tolerance values reduce manufacturing costs, but increase assembly costs, and vice versa. Therefore, it is necessary to determine the optimal permissible tolerance values, Figure 1.

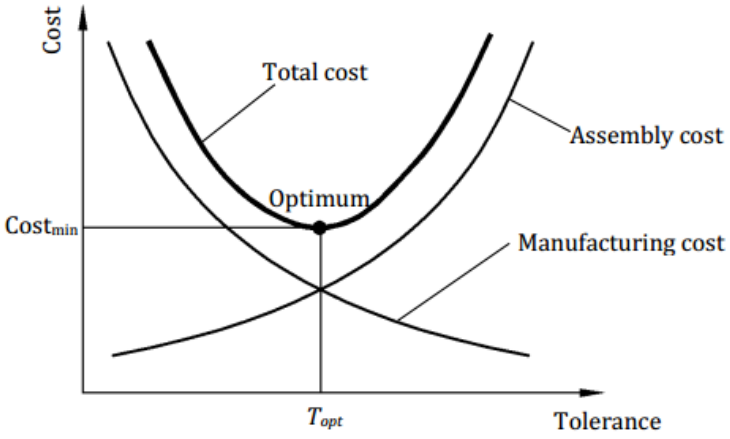


Figure 1. Cost and tolerance optimization.

To determine the value of the permissible tolerances, it is necessary to optimize costs, which in the product design phase implies the introduction of the DFMA approach. DFMA is an acronym for Design for Manufacturing and Assembly. DFMA in this case is a combination of two methodologies: Design for Manufacturing, meaning design for wide tolerances and lower costs, and Design for Assembly, meaning design for tight tolerances and lower assembly costs while executing both ideas at the same time [2,8,9].

Dimensional analysis is used to optimize costs and tolerances and can be solved by one of the interchangeability methods. The complex of scientific and technical fundamental positions, the fulfilment of which during the designing, production and operation phases provides interchangeability of details, assembly units and products is called the principle of interchangeability. Interchangeability of products and their parts is defined as their property to equivalently replace, when using any of set of products copies, their parts or other products with similar copy. The method of complete interchangeability, which takes into account the possibility of the most unfavourable combination of limit deviations of the component dimensions, often results in a very tight (uneconomic) tolerances of these dimensions. In order to achieve better economic efficiency, other methods are used, such as the incomplete interchangeability method and the method of group interchangeability [2,10,11].

3. Method of group interchangeability

The assembly tolerance value of the component link increases several times to an economically viable manufacturing tolerance. After manufacturing, the parts are sorted according to their actual dimensions into groups within the assembly tolerance and are assembled into corresponding groups using the method of complete interchangeability. This method is applicable is mass and large-scale production with small groups (3-4) of assembly tolerances. However, the disadvantages include an increase in the volume of work in progress, additional costs for checking, sorting, and marking parts, and complications in the supply of spare parts [5,11].

With the use of the group interchangeability method the assembly tolerance of the resulting dimension T_n is increased in n times (n is an integer), Figure 2.

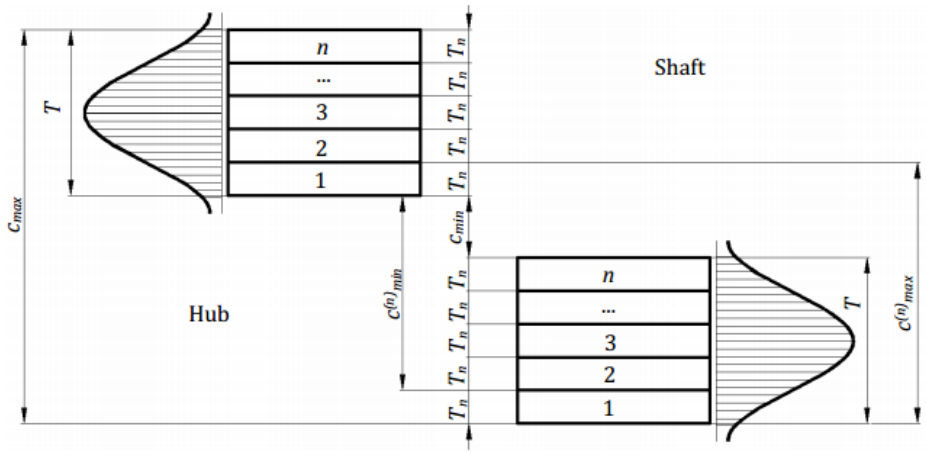


Figure 2. The group interchangeability method on an example the shaft and the hub.

The increased tolerance $T = n \cdot T_n$ is used to calculate the tolerances of the component dimensions. The parts manufactured with such relatively wide tolerances are sorted by size in n groups and each is assigned a number. Then products are assembled of the parts that belong to the same group, which provides the required tolerance value of the resulting dimension T. Thus, when assembling products of the parts belonging to the same group, the resulting dimension tolerance T is ensured by the method of complete interchangeability [2,3,11].

To apply the method of group interchangeability it is necessary to satisfy the following conditions [3,11]:

- Deviation of form and location of the parts shall not exceed the tolerance of their size in the group. Obviously, if this condition is not met, the application of the method of group interchangeability is impossible. The parts that do not met this condition are manufacturing scrap.
- The parts being assembled (shafts and hubs) should have approximately the same (wide) manufacturing tolerances.
- It is necessary that the number of groups (n) be the same, in order to obtain the same (tight) dimensional tolerances of the parts to be assembled (assembly tolerances).
- The manufacturing tolerances as random values have a normal (Gaussian) distribution, because the field of application is mass and large-scale production. The mathematical basis for this assumption is the Central Limit Theorem (CLT), the most important theorem of Probability Theory, Figure 2.

The method of group interchangeability has an important application in assembly interference-fit. Interference-fit joints are commonly used in engineering constructions for connecting the shaft and the hub, Figure 3. Stresses develop between the shaft and the hub due to the contact pressure generated by an interference fit. The interference fit is achieved by pressing a larger inside member (shaft) into the smaller opening of an outside member (hub). The outside diameter of the shaft d_s is slightly larger than the inside hole diameter of the hub d_h. The diametral difference between the shaft outside diameter and the inside diameter of the hub hole is referred to as the interference fit c [12,13].

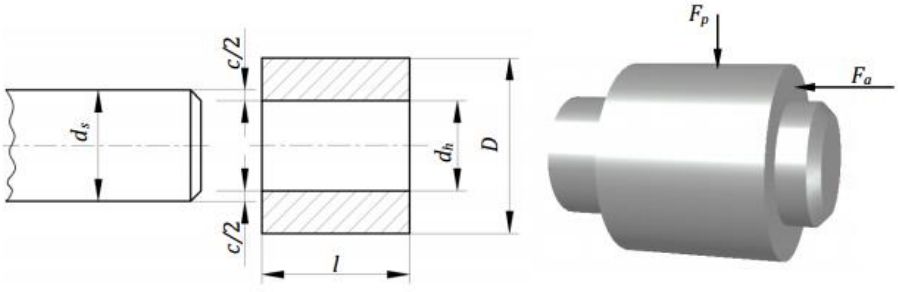


Figure 3. The idea of the interference-fit joint.

The value of minimal axial force breaking the interference-fit joint for wide manufacturing tolerance can be calculated from the following formula [12,13]:

$$F_{a\min} = \pi \cdot d \cdot l \cdot p_{\min} \cdot \mu = \pi \cdot l \cdot \frac{c_{\min} - 1{,}2\left(R_s + R_h\right)}{\left(\xi_e + \xi_i\right)} \cdot \mu \,, \tag{1}$$

where there are as follows:
d - nominal diameter,
l- length of the press-fit joint,
p_{min} - minimal contact pressure,
μ - coefficient of friction of the joined parts contact surfaces,
c_{min} - minimal interference fit for wide manufacturing tolerance, Figure 2,
ξ_e, ξ_i - coefficients depending on the type of material and geometrical relationships,
R_s - roughness coefficient of the shaft,
R_h - roughness coefficient of the hub.

Axial force breaking the interference-fit for assembly tolerance is:

$$F_{a\min}^{(n)} = \pi \cdot l \cdot \frac{c_{\min} - 1{,}2\left(R_s + R_h\right) + \frac{T}{n}\left(n-1\right)}{\left(\xi_e + \xi_i\right)} \cdot \mu \,, \tag{2}$$

where there are as follows, Figure 2:
n - the number of groups,
T-manufacturing tolerance.

Axial assembly force the interference-fit is the minimum force required to assembly the interference - join and it can be calculated from the following equation:

$$F_{aa} = \pi \cdot d \cdot l \cdot p_{\max} \cdot \mu = \pi \cdot l \cdot \frac{c_{\max} - 1{,}2\left(R_s + R_h\right)}{\left(\xi_e + \xi_i\right)} \cdot \mu \,, \tag{3}$$

where there is $p_{\max}$ the maximal contact pressure.

Axial assembly force interference for the assembly tolerance is:

$$F_{aa}^{(n)} = \pi \cdot l \cdot \frac{c_{\max} - 1{,}2\left(R_s + R_h\right) - \frac{T}{n}\left(n-1\right)}{\left(\xi_e + \xi_i\right)} \cdot \mu \,, \tag{4}$$

The axial force breaking the interference-fit for assembly tolerance (2) is greater than axial force breaking the interference-fit for manufacturing tolerance (1). The axial force assembly the interference-fit for assembly tolerance (4) is greater than the axial force assembly the interference-fit for manufacturing tolerance (3). These are, of course, positive consequences of applying the method of group interchangeability on interference-fit joint because by increasing the axial force breaking the interference-fit, a tighter and more stable connection is obtained and by decreasing the axial assembly force less hydraulic or mechanical press power is required.

4. Monte Carlo Simulation

Monte Carlo Simulation is a mathematical technique which is used to estimate the possible outcomes of an uncertain event. It was invented during the Manhattan Project by John von Neumann [1903-1957], Nicholas Metropolis [1915-1999] and Stanislaw Ulam [1909-1984] and named for Ulem's uncle who enjoyed playing games of chance in Monte Carlo, Monaco. This is a probabilistic method based on performing numerous fictive experiments using random numbers. The Monte Carlo method requires the use of a computer because a large number of random variables need to be generated [14,15].

Most of today's random number generators are not based on physical devices but on simple algorithms that can be easily implemented on a computer. These generators are called pseudorandom. Pseudorandom number generators require tests as exclusive verifications for their "randomness," as they are decidedly not produced by "truly random" processes, but rather by deterministic algorithms. Non-parametric hypothesis tests can be used for testing randomness of sequence random numbers. There are several popular types of non-parametric hypothesis tests used in research nowadays: chi-square test, Friedman one, Romanovsky, Kolmogorov-Smirnov one and others [14,16].

It is easy to generate uniformly distributed pseudo-random numbers on a computer. The probability that a uniformly distributed random number falls within any interval of fixed length is independent of the location of the interval itself (but it is dependent on the interval size), so long as the interval is contained in the distribution's support. In MS Excel, the RAND () function is used to generate random numbers in the interval between 0 and 1, as shown in Figure 4.

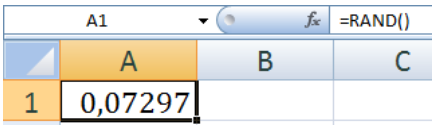


Figure 4. RAND() function in MS Excel.

Random numbers, distributed uniformly in the interval RAND() = $u \in [0;1]$, are the basis for determining random variables. The basic idea is that the cumulative distribution function F for any continuous random quantity x is also random number. If the cumulative distribution function of random quantity x is described by the formula [17]:

$$u = F(x), \tag{5}$$

then the random variables of x can be obtained from the random numbers u with uniform distribution in RAND() = $u \in [0;1]$ using the inverse formula:

$$x = F^{-1}(u). \tag{6}$$

Here, F^{-1} means inverse probabilistic transformation, Figure 5.

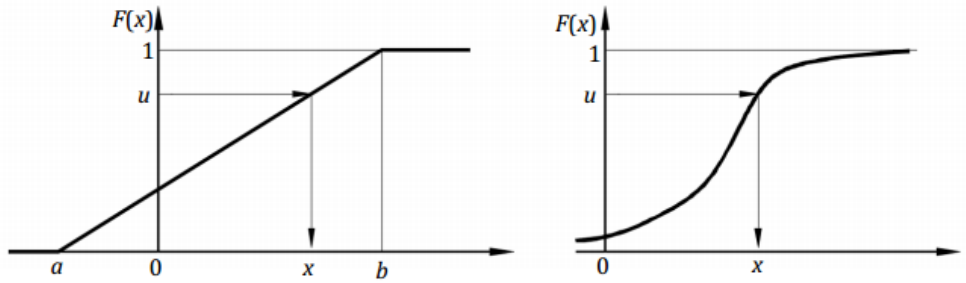


Figure 5. Generation of random variables by inverse probabilistic transformation.

If the function F is distributed uniformly in the interval $[a,b]$, then the calculation of random number x is based on equation, Figure 5 a):

$$x = (b-a) \cdot RAND() + a \,. \tag{7}$$

The cumulative distribution function for normal distribution is, Figure 5 b):

$$u = F(x) = \int_{-\infty}^{x} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \,, \tag{8}$$

with the parameters μ and σ. The inverse transformation for the distribution (8) do not have analytical solution. In MS Excel the value of random variable is obtained from function NORMINV(A2;F1;F2), which is inverse function of normal distribution, and random number, function RAND(), Figure 6. Specific parameter values are shown in cells F1 and F2. In this case the probability is represented by pseudorandom number RAND().

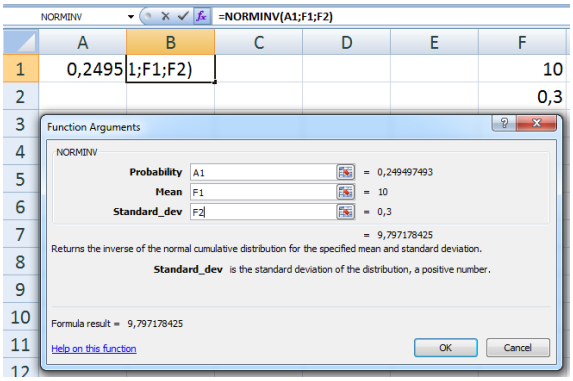


Figure 6. Generation of random variables in MS Excel.

The simulation of a random process is obtained by copying the first row in sufficiently large number of iterations, Figure 6.

1. Example of Monte Carlo Simulation

In this chapter, two types of fits are simulated with the Monte Carlo method.

First, the H8/x8 fit (Figure 7) was simulated as a case where manufacturing tolerances T and assembly tolerances T_n have the same value for group numbers n = 2 - 5. The first assumption is that manufacturing tolerances have a normal distribution (the mathematical basis for this assumption is the Central Limit Theorem), where the standard deviation is:

$$\sigma = \frac{T}{6}, \tag{9}$$

so the probability of manufacturing scrap is 0,0027.

The mean of distribution is the middle of tolerance, Figure 7:

$$\mu_S = \frac{uld + lld}{2}, \tag{10}$$

$$\mu_H = \frac{ULD + LLD}{2}. \tag{11}$$

where there are as follows:
μ_S - mean of the shaft,
μ_H - mean of the hub,
uld - upper limit deviation of the shaft,
lld - lower limit deviation of the shaft,
ULD - upper limit deviation of the hub,
LLD - lower limit deviation of the hub.

The probability of sorting parts is higher for assembly tolerance groups that are closer to the middle of the normal distribution. For n = 2, $p(1) = p(2) = 0{,}499$, where $p(1)$ is the probability that the dimension of a randomly selected part belongs to the first assembly tolerance field, etc. For n = 3, $p(2) = 0{,}682$, $p(1) = p(3) = 0{,}1573$. For n = 4, $p(2) = p(3) = 0{,}433$, $p(1) = p(4) = 0{,}065$. For n = 5, $p(3) = 0{,}452$, $p(2) = p(4) = 0{,}238$, $p(1) = p(5) = 0{,}035$.

The second assumption is that manufacturing tolerances are distributed uniformly in the intervals [*lls*,*uls*] and [*LLS*,*ULS*], Equation (7), Figure 5 a), so the probability of manufacturing scrap is zero, that is, there is no manufacturing scrap. In the literature [2,11], a uniform distribution is described as one that frequently occurs in manufacturing and assembly processes. It is typically observed in approximate manual adjustments or uncontrolled operations, where all values within a given range are equally likely, such as in certain casting or manual fitting operations. The fifth of the conditions for applying the method of group interchangeability mentioned in Chapter 3 is violated here. The probability of sorting parts for a uniform distribution is the same for all assembly tolerance groups and it is:

$$p(n) = \frac{1}{n}, \tag{12}$$

where is n = 2 - 5 - the number of groups.

Second, the H8/x6 (Figure 8) fit was simulated as a case where manufacturing tolerances T and assembly tolerances T_n do not have the same value for the shafts and the hubs. The third of the conditions for applying the method of group interchangeability mentioned in Chapter 3 is violated here. The reason is the determination of the percentage of assembly scrap in this example as well. The normal and uniform distribution assumptions are the same as in the first case for fit H8/x8.

The goal of the simulation is to determine the percentage of assembly scrap, that is, the number of parts (shaft or hub) that do not have a corresponding part (hub or shaft) with which they can be paired and assembled, because there are more hubs than shafts within one group and vice versa. Let the number of shafts within group 1 be n_{1S} and the number of hubs n_{1H}. The ideal case is when $n_{1S} = n_{1H}$. In that case, there is no assembly scrap. If $n_{1S} \neq n_{1H}$, then their difference is the amount of assembly scrap for group 1. This applies to all groups (2-5) of tight tolerances. The theoretical probability of the number of parts within a group is the same, but this does not mean that there are the same number of parts, which is determined by the Monte Carlo simulation method.

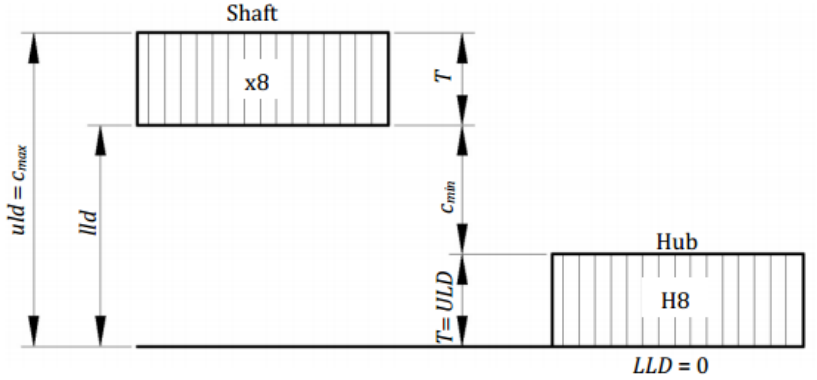


Figure 7. H8/x8 fit.

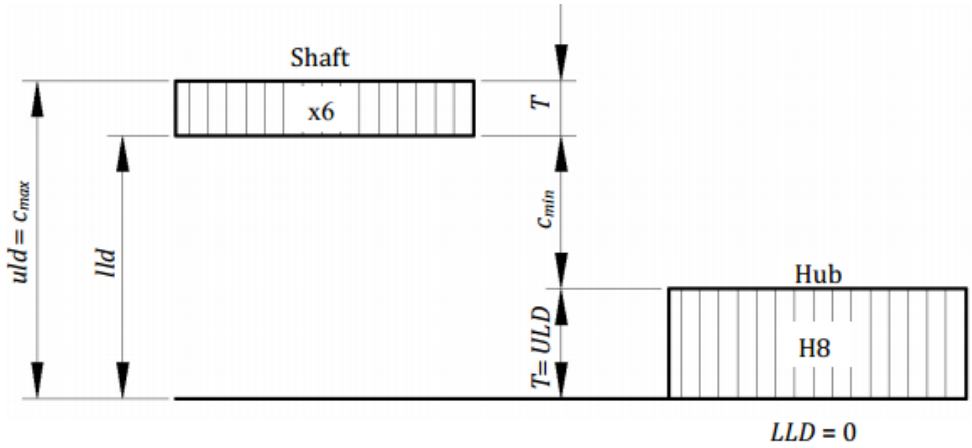


Figure 8. H8/x6 fit.

The first simulation was done for fit H8/x8, with the assumption of a normal distribution of manufacturing tolerance, where is $\mu_S = 145$[µm], $\mu_H = 23$ [µm] and $\sigma = 7{,}667$ [µm]. The standard deviation is the same for both tolerance fields. Manufacturing tolerance is $T = 46$ [µm].

The simulation is done using MS Excel and is shown in the next few steps.

1.Determination of deviations for groups (n = 2-5) of tight tolerances, Table 1.

Table 1. Deviations for fit H8/x8.

Tolerance field x8 T= 46 [µm]				Tolerance field H8 T= 46 [µm]			
		Deviation				Deviation	
T/n	*n*	Lower - *lld*	Upper - *uld*	*T/n*	*n*	Lower - *LLD*	Upper - *ULD*
23	2	145	168	23	2	23	46
	1	122	145		1	0	23
	3	152,6667	168		3	30,66667	46
15,33333	2	137,3333	152,6667	15,33333	2	15,33333	30,66667
	1	122	137,3333		1	0	15,33333
	4	156,5	168		4	34,5	46
	3	145	156,5		3	23	34,5
11,5	2	133,5	145	11,5	2	11,5	23
	1	122	133,5		1	0	11,5
	5	158,8	168		5	36,8	46
	4	149,6	158,8		4	27,6	36,8
9,2	3	140,4	149,6	9,2	3	18,4	27,6
	2	131,2	140,4		2	9,2	18,4
	1	122	131,2		1	0	9,2

2. The values of the random variables for both fields H8 and x8 are determined, according to the assumption of a normal distribution, as shown in Figures 6 and 9. The mean of the hubs and the mean of the shafts are calculated according to the Equations (10) and (11). The deviations are determined in Table 1.

B2 =NORMINV(A2;23;7,66666667)

	A	B	C	D
1	rand()	H8	rand()	x8
2	0,226478	17,2462	0,826727	152,2167

Figure 9. Determination of random variables for tolerance fields.

3. The random variable from the second step is within one of the assembly tolerance groups (2-5) or is outside the manufacturing tolerance due to the assumption of normal distribution. This is determined by a combination of relational and logical operators, as shown in Figure 10.

=IF(AND(D2>=145;D2<168);2;0)

	A	B	C	D	E	F	G	H	I	J	K	L
1	rand()	H8	rand()	x8	1H8	2H8	1H8Err	2H8Err	1x8	2x8	1x8Err	2x8Err
2	0,226478	17,2462	0,826727	152,2167	1	0	0	0	0	2	0	0

Figure 10. Determining the position of random numbers.

If the random variable is inside the first assembly tolerance, the number 1 is written in the cell, etc. If the random variable is outside the manufacturing tolerance, for H8 it is written 10 (below) or 20 (above) and for x8 it is written 30 (below) or 40 (above).

4. Row 2 is copied arbitrary number of times, to get sufficient number of iterations. In this case that number is 50.000, Figure 11. With this, a simulation of a random process was obtained.

5. In this step, it is counted how many random variables are inside one of the assembly fields or outside the manufacturing tolerance, Figure 11.

=COUNTIF(E1:E50001;1)

	A	B	C	D	E	F	G	H	I	J	K	L
50001	0,597525	24,89325	0,498038	144,9623	0	2	0	0	1	0	0	0
50002					24873	24981	73	73	24925	24925	78	72

Figure 11. Counting random numbers

6. The amount of assembly scrap and total scrap is determined in the Table, Figure 12. The difference between cells E50002 and I50002 and cells F50002 and J50002 are assembly scrap. Manufacturing scrap is the sum of cells G50002, H50002, K50002 and L50002. Total scrap is the sum of manufacturing scrap and assembly scrap. Row 50005 shows the amount of scrap, and row 50006 shows the percentage of scrap.

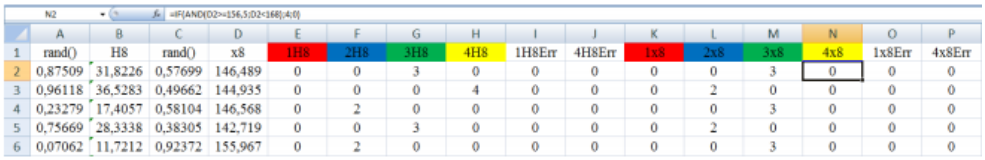
=ABS(E50002-I50002)

D	E	F	G	H	I	J	K	L
134,51969	0	2	0	0	1	0	0	0
	24802	25062	76	63	25023	24828	70	82

	Assembly	Assembly	Σ	Manufacturing
Amount	221	234	**455**	**291**
Percentage	0,442	0,468	**0,91**	**0,582**

Figure 12. Calculation of the amount and percentage of scrap.

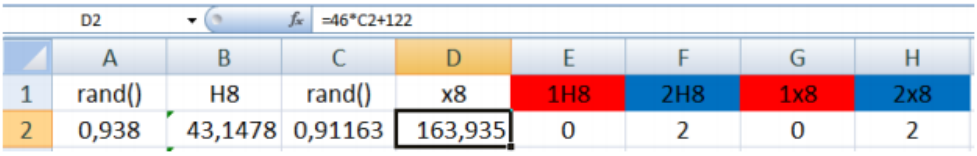
The previously mentioned steps are similar for all groups (2-5) of assembly tolerances, Figure 13.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	rand()	H8	rand()	x8	1H8	2H8	3H8	4H8	1H8Err	4H8Err	1x8	2x8	3x8	4x8	1x8Err	4x8Err
2	0,87509	31,8226	0,57699	146,489	0	0	3	0	0	0	0	0	3	0	0	0
3	0,96118	36,5283	0,49662	144,935	0	0	0	4	0	0	0	2	0	0	0	0
4	0,23279	17,4057	0,58104	146,568	0	2	0	0	0	0	0	0	3	0	0	0
5	0,75669	28,3338	0,38305	142,719	0	0	3	0	0	0	0	2	0	0	0	0
6	0,07062	11,7212	0,92372	155,967	0	2	0	0	0	0	0	0	3	0	0	0

Figure 13. Simulation for four groups of assembly tolerances.

The simulation for fitting H8/x8, assuming a uniform distribution of manufacturing tolerance, is identical to the above procedure, with the difference that there is no manufacturing scrap, Figure 14.



D2 =46*C2+122

	A	B	C	D	E	F	G	H
1	rand()	H8	rand()	x8	1H8	2H8	1x8	2x8
2	0,938	43,1478	0,91163	163,935	0	2	0	2

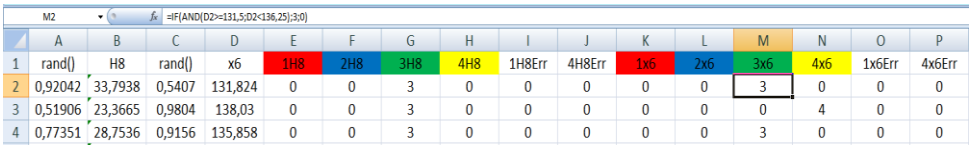
Figure 14. Simulation for uniform distribution of manufacturing tolerance.

The second simulation was done for fit H8/x6, with the assumption of a normal distribution of manufacturing tolerance, where is μ_S= 131,5[µm], μ_H= 23 [µm],σ_S=3,1667 [µm] and σ_H= 7,667 [µm], Table 2.

Table 2. Deviations for fit H8/x6.

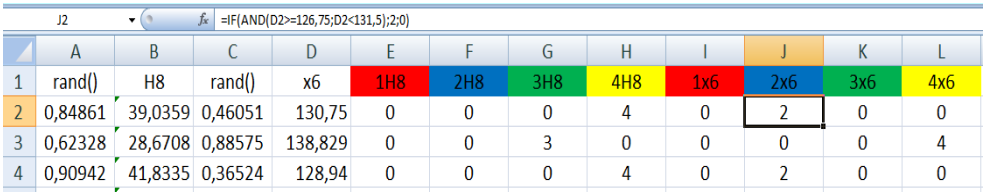
Tolerance field x6 T= 19 [µm]				Tolerance field H8 T= 46 [µm]			
		Deviation				Deviation	
T/n	*n*	Lower - *lld*	Upper - *uld*	*T/n*	*n*	Lower - *LLD*	Upper - *ULD*
9,5	2	131,5	141	23	2	23	46
	1	122	131,5		1	0	23
	3	134,6667	141		3	30,66667	46
6,333333	2	128,3333	134,6667	15,33333	2	15,33333	30,66667
	1	122	128,3333		1	0	15,33333
	4	136,25	141		4	34,5	46
	3	131,5	136,25		3	23	34,5
4,75	2	126,75	131,5	11,5	2	11,5	23
	1	122	126,75		1	0	11,5
	5	137,2	141		5	36,8	46
	4	133,4	137,2		4	27,6	36,8
3,8	3	129,6	133,4	9,2	3	18,4	27,6
	2	125,8	129,6		2	9,2	18,4
	1	122	125,8		1	0	9,2

The simulation for fit H8/x6 (Figures 15 and 16), assuming a uniform and a normal distribution of manufacturing tolerance, is identical to the above procedure, Figures 9 - 14.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	rand()	H8	rand()	x6	1H8	2H8	3H8	4H8	1H8Err	4H8Err	1x6	2x6	3x6	4x6	1x6Err	4x6Err
2	0,92042	33,7938	0,5407	131,824	0	0	3	0	0	0	0	0	3	0	0	0
3	0,51906	23,3665	0,9804	138,03	0	0	3	0	0	0	0	0	0	4	0	0
4	0,77351	28,7536	0,9156	135,858	0	0	3	0	0	0	0	0	3	0	0	0

Figure 15. Simulation fit H8/x6 for normal distribution of manufacturing tolerance.

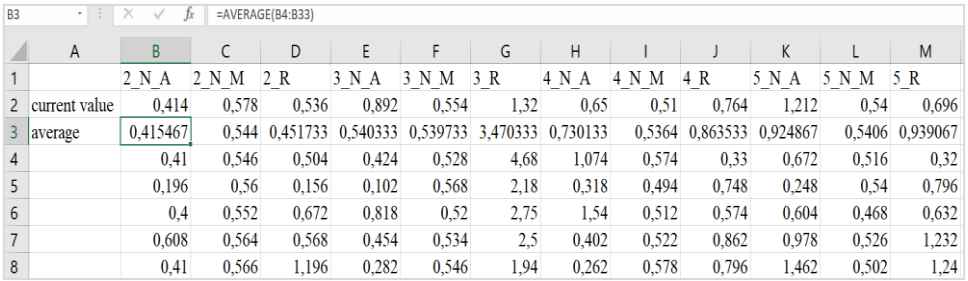


	A	B	C	D	E	F	G	H	I	J	K	L
1	rand()	H8	rand()	x6	1H8	2H8	3H8	4H8	1x6	2x6	3x6	4x6
2	0,84861	39,0359	0,46051	130,75	0	0	0	4	0	2	0	0
3	0,62328	28,6708	0,88575	138,829	0	0	3	0	0	0	0	4
4	0,90942	41,8335	0,36524	128,94	0	0	0	4	0	2	0	0

Figure 16. Simulation fit H8/x6 for uniform distribution of manufacturing tolerance.

The last step and goal of the simulation is to determine the final percentage of assembly scrap and manufacturing scrap.

Due to the different arrangement of random numbers in columns A and C that occurs with each change in MS Excel (e.g. by activating the delete function), different random variables are also obtained in columns B and D, so that the calculated amount of assembly scrap and manufacturing scrap, and therefore the percentages of scrap, also changes. Therefore, the average value of at least 30 such current values is taken as relevant, Figure 17.



	A	B	C	D	E	F	G	H	I	J	K	L	M
1		2_N_A	2_N_M	2_R	3_N_A	3_N_M	3_R	4_N_A	4_N_M	4_R	5_N_A	5_N_M	5_R
2	current value	0,414	0,578	0,536	0,892	0,554	1,32	0,65	0,51	0,764	1,212	0,54	0,696
3	average	0,415467	0,544	0,451733	0,540333	0,539733	3,470333	0,730133	0,5364	0,863533	0,924867	0,5406	0,939067
4		0,41	0,546	0,504	0,424	0,528	4,68	1,074	0,574	0,33	0,672	0,516	0,32
5		0,196	0,56	0,156	0,102	0,568	2,18	0,318	0,494	0,748	0,248	0,54	0,796
6		0,4	0,552	0,672	0,818	0,52	2,75	1,54	0,512	0,574	0,604	0,468	0,632
7		0,608	0,564	0,568	0,454	0,534	2,5	0,402	0,522	0,862	0,978	0,526	1,232
8		0,41	0,566	1,196	0,282	0,546	1,94	0,262	0,578	0,796	1,462	0,502	1,24

Figure 17. Determine the final percentages of assembly scrap and manufacturing scrap.

The percentages of scrap for fit H8/x8 and fit H8/x6 are shown in Table 3 and Figures 18 and 19.

Table 3. Percentages of scrap [%].

Group *n*	2		3		4		5	
Distribution	Normal	Uniform	Normal	Uniform	Normal	Uniform	Normal	Uniform
Fit				H8/x8				
Assembly	0,42	0,45	0,54	3,47	0,73	0,86	0,92	0,94
Manufactur.	0,54	-	0,54	-	0,54	-	0,54	-
Total	0,96	0,45	1,08	3,47	1,27	0,86	1,46	0,94
Fit				H8/x6				
Assembly	0,45	0,54	0,64	3,73	0,80	0,94	0,91	1,06
Manufactur.	0,54	-	0,54	-	0,54	-	0,54	-
Total	0,99	0,54	1,08	3,73	1,34	0,94	1,45	1,06

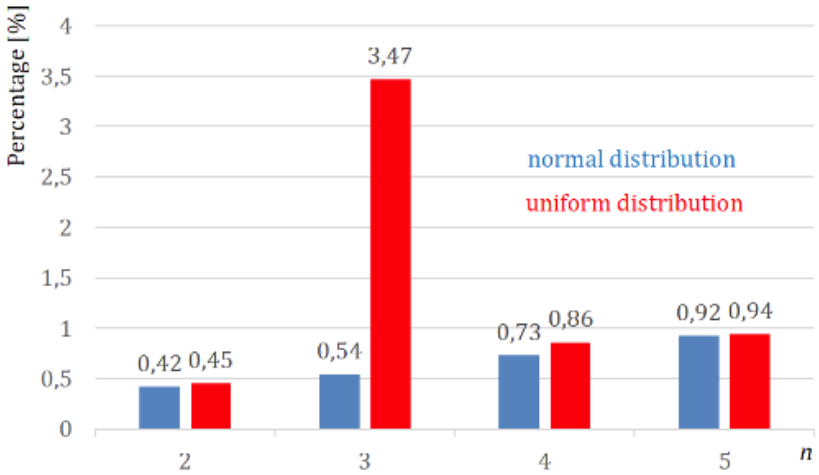


Figure 18. Percentages of assembly scrap for fit H8/x8

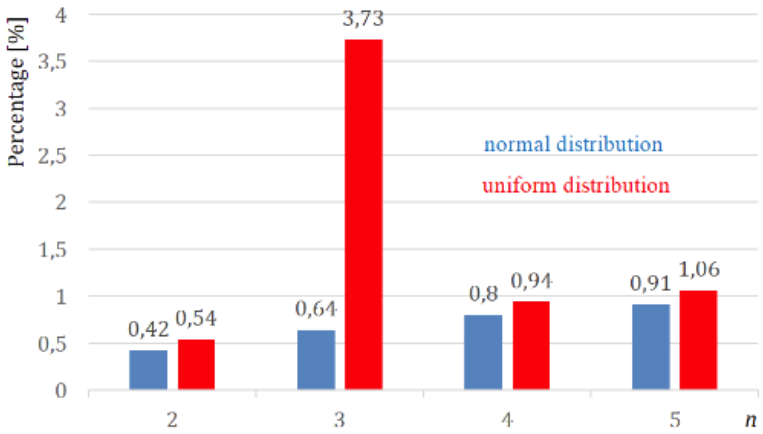


Figure 19. Percentages of assembly scrap for fit H8/x6.

All percentages of manufacturing scrap are 0,54 %, which is expected because the probability of manufacturing scrap is 0,0027 as a consequence of Equation (6). The percentage is twice the probability because the percentage is calculated for both the shaft and the hub.

For normal distribution, with an increase in the number of groups, the percentage of assembly scrap also increases, for both fits, which is the expected result.

For a uniform distribution, there is an unexpected increase in the waste percentage for n = 3. The probability of sorting parts into all three groups is 0,333, so the reason is inexplicable and subject to future investigations.

1. Conclusion

Permissible tolerances have an influence on manufacturing and assembly costs differently. Wide tolerance values reduce manufacturing costs, but increase assembly costs, and vice versa. Therefore, it is necessary to determine the optimal permissible tolerance values or apply the interchangeability method in the case of mass and large-scale production. In the case of the application of the interchangeability method, the problem of assembly scrap arises, that is, the amount of unpaired parts within the same assembly tolerance groups. With the Monte Carlo method, it is easy to determine the simulated amount or percentage of assembly scrap.

Simulation with the Monte Carlo method is a simple and reliable process. By using the widely available MS Excel program, which is user friendly because of the accessible interface, mistakes are immediately shown without mistrust of background calculations and possible code errors. The Monte Carlo simulation method is a numerical stochastic model, which requires a large iteration number. Although the iteration

number is arbitrary, for optimization application it should be at least 10^4 order, in this paper it is $5 \cdot 10^4$. The disadvantage of Monte Carlo optimization is inaccuracy which can be eliminated by increased number of iterations.

The assumption that manufacturing tolerances have a normal distribution has no influence on the simulation, i.e. the percentage of assembly scrap does not depend on the probabilities mentioned in chapter 5. In this case, assembly scrap increases with the increase in the number of assembly tolerance groups, where the percentage of assembly scrap does not exceed 1%.

The same can be concluded for the uniform distribution, except for $n = 3$, where the percentage of assembly waste is over 3% for an unknown reason.

In conclusion, it can be stated that the type of fits (H8/x8 or H8/x6), i.e. that the first three conditions for applying the method of group interchangeability mentioned in Chapter 3, have no influence on the percentage of assembly scrap.

Excel screenshots, accompanied by detailed explanatory paragraphs, are included to enable readers to independently construct simulations for any type of fit or distribution based on the proposed technique.

The mentioned technique, procedure, and results can be applied in real production, especially with the assumption of normal distribution manufacturing tolerance.

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Mathematical modeling of the roughness of the laser cutting process

Husein Rošić[1], Tina Hušidić[1], Hasan Talić[1] and Samira Hotić[2]

[1] Faculty of Technical Engineering, University of Bihać, Bihać, Bosnia and Herzegowina
[2] Faculty of Biotechnical Engineering, University of Bihać, Bihać, Bosnia and Herzegowina

*E-mail: husein.rosic@unbi.ba

Abstract. Laser cutting is one of the more attractive unconventional processing technologies that is increasingly being used in industry due to its efficiency. From a technological perspective, laser cutting technology is a very complex process. In order to obtain the required processing quality, reduce costs and increase productivity, it is necessary to determine the relationship between the process factors of the mathematical model of laser cutting. The paper will present experimental data obtained from research on three different types of materials: galvanized sheet metal, black sheet metal and stainless steel. We will use sheet metal thicknesses of 1.5, 2 and 2.5 mm. By applying an orthogonal plan, a mathematical model of the dependence of the roughness of the cut surface on power, cutting speed and material thickness was created.

Key words: laser cutting, roughness, mathematical model, cutting speed, power

1. Introduction

Laser cutting is an industrial process for a very wide range of materials and thicknesses. It is one of the more attractive unconventional processing technologies that is increasingly being used in industry. It is based on the application of highly concentrated light energy, obtained by laser radiation, to process materials by melting or vaporizing. Laser cutting from a technological aspect is a very complex process of interactions between a laser beam, an assist gas and the workpiece material. It is a very efficient method for precise contour cutting of materials that has a number of advantages over other contour cutting processes, including a narrow cut, minimal heat-affected zone, a regular cut profile, high quality of the cut surface, minimal deformation of the workpiece, high productivity, the ability to cut complex shapes, low noise, a high degree of automation and flexibility [1].

The word "laser" is an acronym for light amplification by stimulated emission of radiation. It was first proposed by Schawlow and Townes [2]. A laser must have the following basic components, figure 1.:

1. active medium, which serves as a means to amplify light;
2. pumping source, which is a means to excite the active medium to the amplifying state and
3. optical resonator, which is a means to provide optical feedback.

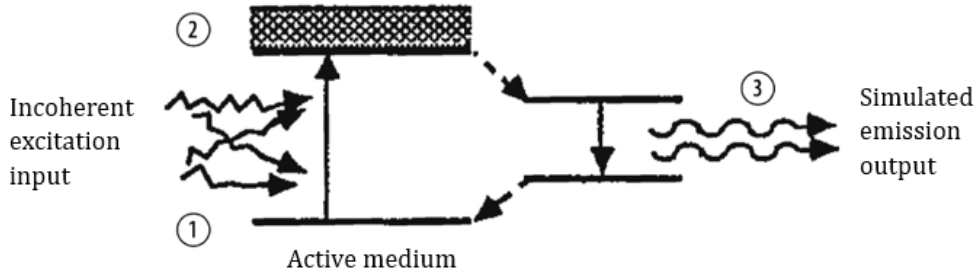

Figure 1. Energy level diagram for a four-level laser system showing the means to amplify light [3].

Laser processing (Laser Beam Machining – LBM) is a process of processing materials by welding, melting or vaporizing using a laser, i.e. highly concentrated light energy generated by stimulated radiation. By focusing the laser beam, an extremely high power density is achieved (over 10^8 W/cm^2), which enables melting or vaporizing the material in a very short time interval.

Laser cutting occurs due to the relative movement of the focused laser beam in relation to the workpiece. At the same time, a jet of auxiliary gas acts coaxially with the beam, which removes the molten material from the cutting zone, figure 2. This gas has additional functions: it protects optical components, primarily the lens, from contamination by vapors, and eliminates the plasma cloud that can form at high radiation intensity [1].

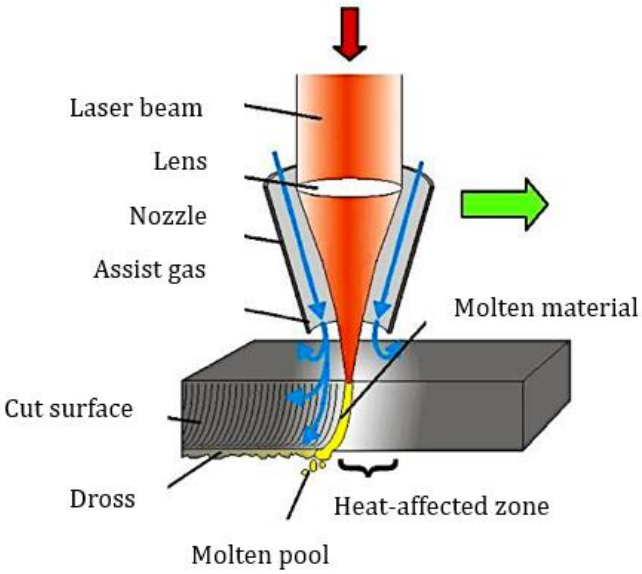

Figure 2. Laser cutting principle [1].

A large number of factors affect the laser cutting process, i.e. cutting performance, such as processing quality, productivity and cost-effectiveness. Some of these factors are laser power, cutting speed, assist gas pressure, focal position, laser and laser beam characteristics, as well as material characteristics and material surface condition.

In order to ensure the achievement of the required processing quality, reduce costs and increase productivity, it is necessary to quantify the relationships between factors and process performance through mathematical modeling. Based on the established laws, it is possible to perform a detailed analysis of the influence of factors on process performance, identify approximately optimal values of process factors and manage the laser cutting process for better efficiency and processing quality [1].

2. Materials and methods

In order to determine the roughness of laser cutting process, a 100x50 mm plate was cut from three different types of material: galvanized sheet metal (DX51DZ Z275), black sheet metal (DC01-1.0330) and stainless steel (X5 CrNi18-10-1.4301) with thicknesses of 1.5, 2.0 and 2.5 mm. The basic properties of these materials are shown in table 1.

The laser cutting operations of plates were performed using a HyperCUT GreenLINE 3.0 V4 fiber laser machine with laser power of 3kW. The cut plates and the laser are shown in figure 3.

Table 1. Basic properties of materials.

MATERIALS	PROPERTIES			
	PHYSICAL	MECHANICAL		
	Density ρ [g/cm^3]	Elongation A [%]	R_m [MPa]	$R_{p0,2}$ [MPa]
DX51DZ Z275	7.85	38	355	245
DCO1 (1.0330)	7.85	28	270-410	280
X5 CrNi18-10 (1.4301)	7.9	45	500-700	195

Figure 3. Cut plates and laser machine.

This laser can cut structural steel up to 16 mm, stainless steel up to 8 mm, aluminium up to 5 mm and galvanized sheet metal up to 6 mm.

Table 2. shows a plan of cutting the plates with 20 different experiments and input factors.

Table 2. Matrix plan.

Number of experiments	Laser power, P[kW]	Cutting speed, v [m/s]	Material thickness , b[mm]
1	1,2	2	1,5
2	2	2	1,5
3	1,2	3	1,5
4	2	3	1,5
5	1,2	2	2,5
6	2	2	2,5
7	1,2	3	2,5

8	2	3	2,5
9	1,6	2,5	2
10	1,6	2,5	2
11	1,6	2,5	2
12	1,6	2,5	2
13	1,6	2,5	2
14	1,6	2,5	2
15	0,93	2,5	2
16	2,3	2,5	2
17	1,6	1,66	2
18	1,6	3,4	2
19	1,6	2,5	1,2
20	1,6	2,5	2,9

Surface Roughness Tester TMR120 was used to measure the results of the experiment, i.e. the roughness of the cut, shown in figure 4.

Figure 4. Surface Roughness Tester TMR120.

This device is an optimized electric circuit design with transducer structure-design and high integrate power. It could test ex-circle, flat surface and conical surface. It has a measurement range (mm) of: Ra: 0.05 ~ 10.0; Rz: 0.1 ~ 50. The main metric used for analysis was *Ra* in μm (average surface roughness), measured at three points on each cut edge. The mean value was taken as the representative roughness for each experiment.

3. Results and discussion

The significance of the mathematical model was checked using the ANOVA table in the Design-Expert software package. The results of this analysis are shown in the table 3.

Table 3. Roughness Ra

Source	Sum of Squares	df	Mean Square	F-value	P-value	
Model	23.59	9	2.62	4.24	0.0170	**significant**
A-Power	10.06	1	10.06	16.29	0.0024	
B-Cutting speed	0.3250	1	0.3250	0.5260	0.4849	
C-Material thickness	0.1603	1	0.1603	0.2594	0.6216	
AB	0.0253	1	0.0253	0.0410	0.8437	
AC	1.27	1	1.27	2.06	0.1819	
BC	0.2080	1	0.2080	0.3366	0.5746	
A^2	4.84	1	4.84	7.83	0.0188	
B^2	0.3423	1	0.3423	0.5540	0.4738	
C^2	5.24	1	5.24	8.48	0.0155	
Source	Sum of Squares	df	Mean Square	F-value	P-value	
Residual	6.18	10	0.6179			
Lack of Fit	4.94	5	0.9873	3.97	0.0782	**not significant**
Pure Error	1.24	5	0.2486			

The **Model F-value** of 4.24 implies the model is significant. There is only a 1.70% chance that an F-value this large could occur due to noise.

P-values less than 0.0500 indicate model terms are significant. In this case A, A^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve this model.

The **Lack of Fit F-value** of 3.97 implies there is a 7.82% chance that a Lack of Fit F-value this large could occur due to noise. Lack of fit is not desirable - we want the model to fit. This relatively low probability (<10%) is troubling.

In order for the resulting coded model to be fully accepted, it is necessary to examine the adequacy of the mathematical model itself, i.e. whether the output parameters calculated from the model correspond to the output parameters of the experiment. This comparison is given in table 4.

Table 4. Fit statistics

Std. Dev.	0.7861	**R^2**	0.7924
Mean	6.29	**Adjusted R^2**	0.6056
C.V. %	12.50	**Predicted R^2**	-0.3271
		Adeq Precision	8.9430

A negative **Predicted R^2** implies that the overall mean may be a better predictor of response than the current model. In some cases, a higher order model may also predict better.

Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Obtained ratio of 8.943 indicates an adequate signal which means this model can be used to navigate the design space.

The form of the mathematical model is given by the following final equation in terms of actual factors:

Roughness Ra = -4.77810-9.04548*A*+3.62188A^2-2.41254C^2.

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

Figure 5. shows a "Predicted vs. Actual" scatter plot used to evaluate the accuracy of a regression model — in this case, for predicting surface roughness (Ra). Model performs better at lower and mid-range values, but struggles slightly with very high roughness, which is seen by the red point.

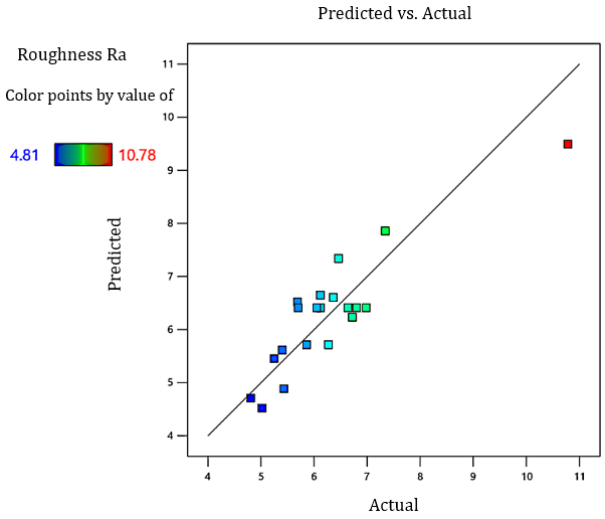

Figure 5. Predicted vs. Actual plot.

The figure 6. shows the dependence of roughness (*Ra*) on laser power (A: Power, in kW) in the laser cutting process, with fixed values of other parameters (B = 2.5, C = 2).

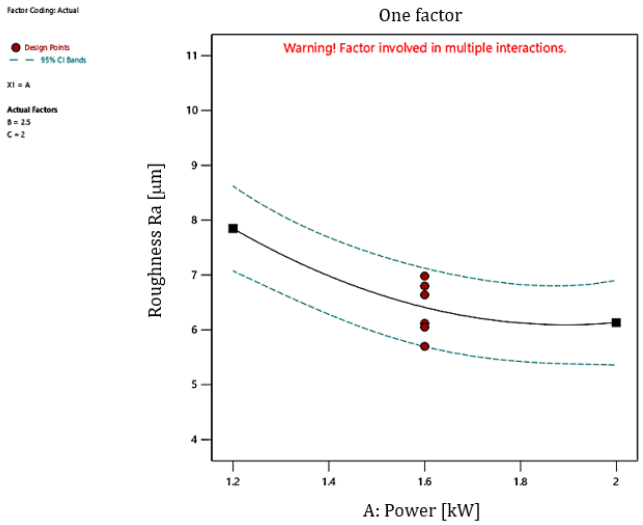

Figure 6. Dependence of roughness on cutting power.

The graph shows a nonlinear decrease in roughness *Ra* with increasing laser power, suggesting that higher power contributes to more efficient cutting of the material, resulting in a smoother surface. The experimental data (red dots) show a good fit to the modeled curve, confirming the validity of the regression model in the range shown. Red warning text indicates that laser power (factor A) is involved in multiple interactions with other factors (B and C), so caution is needed when interpreting a one-factor analysis.

4. Conclusions

A mathematical model was developed using an orthogonal experimental design to analyze the relationships between surface roughness and factors such as laser power, cutting speed, and sheet thickness of different materials. The analysis confirmed that several model terms significantly influence surface roughness and that the model was overall satisfactory and suitable for process optimization within the tested design space. While the model is useful for predicting surface roughness based on given input parameters, its predictive accuracy may be limited in certain conditions which means the model didn't meet the goals we set and some improvements and optimizations are needed.

In conclusion, the developed model provides some valuable insights into the laser cutting process and could be used as a foundation for optimizing cutting conditions to achieve improved surface quality and process efficiency.

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The adventages of 3D modelling in the design of mechanical parts

Ajla Husanović[1]*, Nejra Sulić[1] and Aldin Dedić[1]

[1] Faculty of Technical Engineering, University of Bihac, Bosnia and Herzegovina

E-mail: ajlahusanovic85@gmail.com

Abstract: Due to the need for faster product development in the mechanical industry, the usage of modeling software has grown significantly. CATIA is a popular software application that allows users to create quick and easy creation of 2D and 3D objects. This software also allows you to integrate 3D elements into an assembly, simulate the assembly's operation, and, finally, do stress analysis. This paper shows how to model a piston and connecting rod assembly in CATIA V5 and simulate its operation. To better demonstrate functioning, the model was created using a 3D printer.

1.Introduction

CATIA (Computer Aided Three-dimensional Interactive Application) is a sophisticated CAD (Computer-Aided Design) software developed by Dassault Systèmes, enabling engineers and designers to create, analyze, and optimize products in a 3D environment. It is intended for engineers and designers across various industries, including mechanical engineering, aerospace, automotive, and construction. CATIA supports collaborative work and integrates with the 3DEXPERIENCE platform to enable a complete digital transformation of the product development process. CATIA offers powerful and intuitive tools for complex surface modeling, kinematic analysis, visualization, and reverse engineering, fostering innovation and creativity in design. It is used by numerous renowned global companies such as Boeing, Airbus, BMW, and Rimac.

2. Piston and Connecting rod assembly

The piston and connecting rod are key components of the reciprocating mechanism within an internal combustion engine. Their primary function is to convert the energy generated by fuel combustion into useful mechanical motion.

The piston moves linearly within the cylinder, transferring force through the connecting rod to the crankshaft, where this linear motion is converted into rotational motion. The piston consists of the piston head, rings (which ensure sealing between the piston and the cylinder), and the connecting rod, which is connected to the piston via a piston pin (gudgeon pin) and to the crankshaft at its lower end through a bearing[1]. Figure 1 shows a schematic representation of the piston and connecting rod.

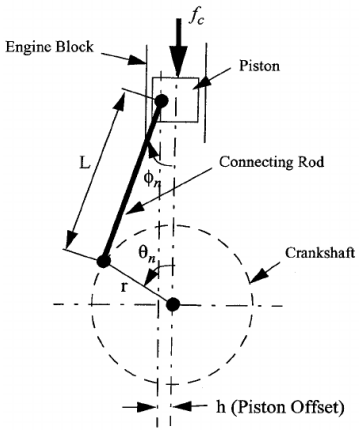

Figure 1. Piston and connecting rod.

The materials used for manufacturing these components must withstand high temperatures, pressures, and forces—typically aluminum alloys for pistons and steel for connecting rods.

2.1 Piston

The piston is one of the most important components of an internal combustion engine, and its main function is to transfer the force generated by the combustion of the fuel-air mixture to the connecting rod.Located within the cylinder, the piston moves in a straight up-and-down motion (known as reciprocating motion). At the top of the piston is the piston head, which is directly exposed to the combustion pressure. Around the piston head are piston rings, which serve to seal the space between the piston and the cylinder wall, preventing the leakage of gases and oil.The inner part of the piston contains an opening for the piston pin (gudgeon pin), which enables the connection to the connecting rod [1]. Pistons are usually made of aluminum alloys, as these provide a lightweight structure and good thermal conductivity—crucial due to the high temperatures inside the engine.Figure 2 shows the piston and its components.

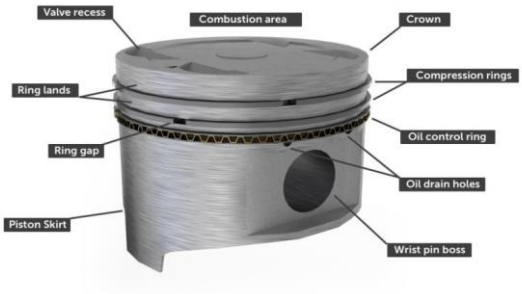

Figure 2. Piston.

In practice, there are various types of pistons, but fundamentally, all pistons can be classified into several groups based on the following criteria:

1. According to their application**:**
   - Pistons for internal combustion engines
   - Pistons for compressors
   - Hydraulic pistons
2. According to their cooling method**:**
   - Solid pistons
   - Internally cooled pistons
3. According to the shape of the piston crown**:**
   - Flat-top piston
   - Recessed piston
   - Domed or crown-shaped piston
4. According to the material:
   - Aluminum pistons
   - Steel pistons
   - Forged pistons

2.2. Connecting rod

The connecting rod is a mechanical component that links the piston to the crankshaft in an internal combustion engine. Its primary function is to transfer the force generated by the combustion of the fuel-air mixture in the cylinder from the piston to the crankshaft, converting the piston's linear motion into the rotational motion of the crankshaft. It is made of high-strength steel or aluminum alloys to withstand the

high compressive and tensile forces, as well as the elevated temperatures present in the engine. The connecting rod must be precisely balanced to reduce vibrations and ensure the engine's longevity.

High-quality manufacturing and proper maintenance of the connecting rod are essential for efficient and reliable engine operation. Figure 3 shows the connecting rod.

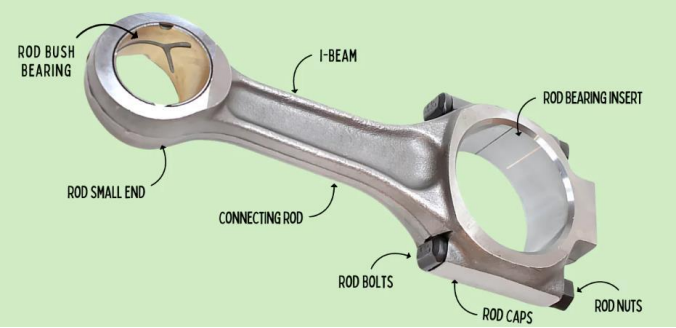

Figure 3. Connecting rod.

In practice, types of connecting rods vary based on their construction, material, and application. They can be classified into the following categories:

- One-piece connecting rods
- Split connecting rods (two-piece)
- Monoblock connecting rods
- Connecting rods with bearings instead of bearing bushings
- Connecting rods with oil channels

2. Modeling in CATIA

Modeling in CATIA refers to the process of creating three-dimensional (3D) models of technical parts and assemblies using advanced CAD tools. This software enables parametric modeling of solid bodies, the shaping of complex surfaces, sheet metal component design, and much more—making it highly suitable for engineering in the automotive, aerospace, and other industries.

By using modules such as Part Design, Generative Shape Design, and Assembly Design, users can accurately shape components, analyze their interrelationships, and efficiently implement changes thanks to parameter linking.

CATIA stands out for its ability to integrate design, simulation, and manufacturing into a single environment, greatly facilitating the development of complex products. Since the piston and connecting rod assembly is complex, it is necessary to model all its elements. All components were created in CATIA and are presented in the remainder of this work.

2.2. Piston modeling

During piston modeling, we first selected Part Design within Mechanical Design. The tools used included:

- Line
- Circle
- Shaft
- Pocket

Figure 4 shows piston modelled in CATIA V5.

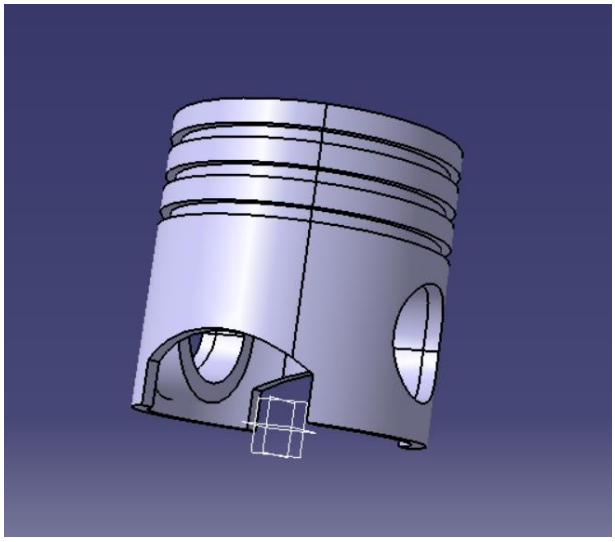

Figure 4. Piston.

2.3. Connecting rod modelling

The connecting rod was modeled within Mechanical Design, where we selected the Part Design workbench. The tools and features used during the modeling process included:

- Circle
- Pad
- Line
- Mirror
- Edge Fillet
- Pocket
- Properties

These tools allowed us to define the geometry, apply symmetrical features, add fillets to edges for smoother transitions, and create necessary cutouts and holes in the connecting rod. Figure 5 show the connecting rod.

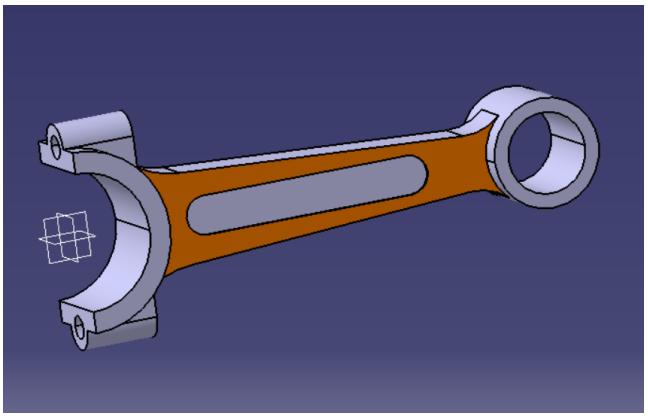

Figure 5. Connecting rod.

2.4. Modelling the connectin rod cap

For modeling the connecting rod cap, we used the following tools:

- Circle

- Pad
- Line
- Pocket
- Mirror

The connecting rod cap was modeled based on the dimensions of the connecting rod and the diameter of the piston pin. These features ensured that the cap precisely fits with the lower end of the connecting rod, maintaining proper alignment and structural integrity within the assembly. Figure 6 shows the connectin rod cap.

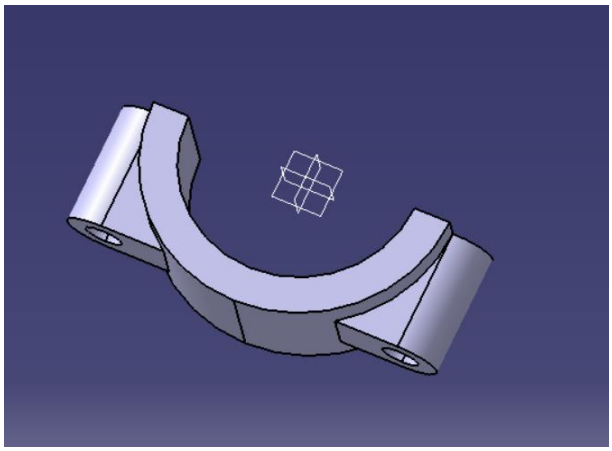

Figure 6. Connecting rod cap.

2.4. Other parts
The piston ring was modeled in **Part Design**. The tools used included:

- Circle
- Pad
- Line
- Pocket
- Properties

Figure 7 shows the piston ring**.**

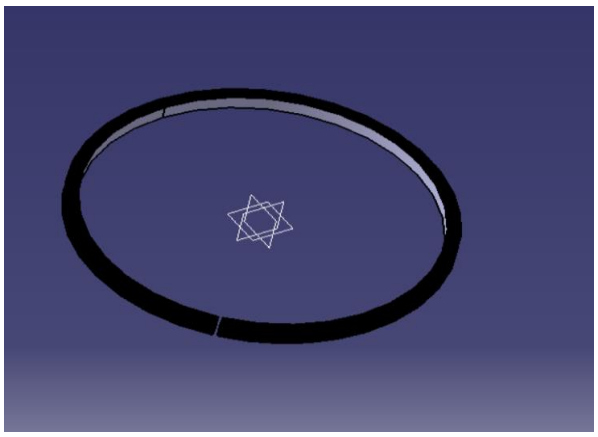

Figure 7. Pistong ring.

The rings were modeled based on the groove dimensions on the piston, ensuring an accurate fit within the piston assembly. We modeled the piston pin in Mechanical Design by selecting Part Design. The tools used included:

- Circle
- Pad
- Chamfer
- Properties.

Piston pin is showed in figure 8.

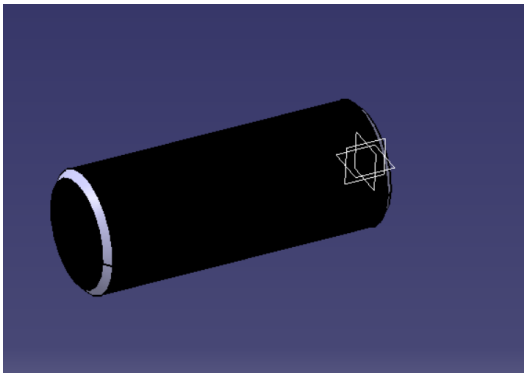

Figure 8. Piston pin.

3. Assembly

The following figure 9 shows the piston and connecting rod assembly. The assembly was created using the **constraint** command by joining parts through their axes or contact surfaces.

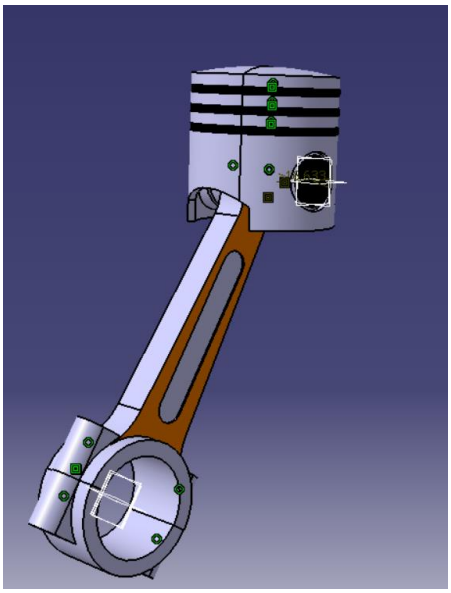

Figure 9. Piston and connecting rod.

It is important to note that the piston rings and piston are concentric relative to each other and connected by their contact surfaces, while the connecting rod is connected to the piston pin by aligning their axes and

contact. The connecting rod cap is attached to the connecting rod only by a contact surface and is fixed in place.

4. 3D printer

Nowadays, 3D printers are powerful tools that aid in better visualization of a workpiece. By printing a specific mechanical part on a 3D printer, it becomes easier to get a real-life representation of the part's appearance and to identify potential errors in any part of the assembly. One of the well-known 3D printer models is the Creality Ender-3 V3, which is shown in the following figure 10.

Figure 10. 3D printer.

It features a printing speed of up to 600 mm/s and automatic calibration, eliminating the need for manual adjustment before printing starts. It is compatible with various filaments, which makes printing easier and more versatile. Printing data can be transferred via USB, Wi-Fi, or through Creality Cloud.

5. Conclusion

This paper presents in detail the process of modeling a piston and connecting rod assembly using CATIA CAD software. Using modules such as Part Design and various tools such as Line, Circle, Shaft, Pad, Pocket, Mirror and Edge Fillet, all key parts of the assembly were created. CATIA has proven to be a very powerful tool for creating complex 3D models, enabling high precision and efficiency in design. Thanks to parameterization and a modular approach, working in CATIA allows for easy adaptation and modification of the model, which is of particular importance in engineering development. Modeling a piston and connecting rod through this process provides a clear picture of the importance of CAD tools in modern technical drawing and design.

After modeling, the assembly was ready to be rendered in STL format in preparation for 3D printing. This phase enabled the physical creation of the model using additive technologies, which further confirms the applicability and usefulness of digital modeling in the real production process.

The combination of advanced CAD modeling and 3D printing shows how modern technologies enable faster product development, simpler prototyping and better validation of construction solutions. This process provides valuable insight into the entire journey – from idea to physical product – which is of utmost importance in today's engineering practice.

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The importance of testing, analysis and safety assessment of working machine cabin structures

Belma Islamović Čavkić*, Ermin Bajramović

Mechanical Engineering, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina

*E-mail: belma.islamovic.cavkic@unbi.ba

Abstract. The need for testing structures, regardless of their type, primarily relates to verifying the quality of workmanship and ensuring that the product meets all necessary safety standards. Any structure or machine in operation can become potentially hazardous to users. When it comes to working machine cabins, safety primarily refers to the protection of the operator in the event of the structure overturning or hitting other objects during operation. Therefore, it is necessary to conduct comprehensive tests before putting the product into service to ensure its reliability. Early detection of defects in the design of working machine cabins allows for quick and economical correction, thus optimizing costs and increasing safety. This paper analyzes in detail the procedures for checking the safety of working machine cabins through tests that include non-destructive methods, as well as destructive methods. Special focus is placed on tests that assess the resistance of the cabin in the event of rolling over of working machines (ROPS) or hitting external objects (FOPS), thus ensuring the reliability and protection of the operator in extreme situations.

1. Introduction

Given the frequent cases of everyday injuries at work caused by faulty machines (either due to the intentional removal of protective devices or malfunctions resulting from poor maintenance or wear and tear of the machines themselves), testing of machines and devices is of great importance for workplace safety [1].

A high level of protection should be achieved without imposing significant restrictions on the use of machines or industrial production. By applying internationally agreed regulations, people and the environment should be protected at the same level in all countries, and any differences in safety requirements should be eliminated where possible [2]. In other words, the basic rules for occupational safety include all technical protection measures on machines and devices. This means that all machines for which these rules fail to eliminate the danger to the worker represent an increased risk [1].

To take effective preventive measures, it is necessary to have complete information about the machines and their operating conditions. For ensuring operator safety in mobile work machines, the protective structure plays a crucial role. Even the smallest change in the structure requires going through a verification and certification process of the proposed solutions, which encourages innovation [3].

To assess the strength of the cabin structure, during the verification of a solution or for periodic inspections, destructive tests are performed to confirm the operator's safety. Since construction and agricultural machinery, due to their intended use, are exposed to hazards such as falling objects on the cabin roof or overturning during work accidents, the tests focus on two main components: FOPS (Falling Object Protective Structures) and ROPS (Rollover Protective Structures).

Engineers continually strive to develop new ideas for additional components or adaptations of existing ones, introducing innovations in the design of working machines. Latorre-Biel et al. focused their research on evaluating safety when using metal discs at the cabin support points and concluded that half of the deformation energy was absorbed by the discs, resulting in a 50% increase in safety [4]. Motivated by this concept, Song et al. conducted tests on rubber discs and found that stress decreases with an increasing number of loading cycles and the amount of deformation [5].

Since the mass of the cabin affects the overall stresses during accidents of this type, some authors have investigated the optimal thickness of the cabin roof while still maintaining its primary function. Ramonal et al. concluded in their study that reducing the roof thickness compromises basic safety requirements and that a greater thickness must be maintained [6]. Other researchers, such as Gheorghe et al., propose solutions involving alternative materials with similar density but higher tensile strength compared to those

materials that failed the FOPS and ROPS tests [7]. This approach optimizes the overall weight of the machine.

The advancement of computer technologies has also led to software capable of producing accurate results with minimal deviations compared to costly real destructive tests. Numerous authors have compared experimental results with software simulations. For example, Vincze et al. developed simulations to compare with actual results and created an appropriate model [3]. Similarly, Kumar et al. iterated their design until all requirements were met within the specified limits, resulting in a more reliable and safer product [8].

Agius et al. explained in their paper how the introduction of softening elements within simulations leads to improved results with increased accuracy [9]. Dumitrache et al. discussed the advantages of using numerical analyses based on FEM, enabling sustainable and frequent testing of this type of structure [10].

This paper will provide a detailed explanation of the legal frameworks related to the use of construction and agricultural machinery, clearly describe the fundamental tests conducted on cabin structures to verify their resistance and reliability, and highlight their role and importance from the perspective of operator safety, with particular emphasis on the necessity to comply with relevant technical and safety standards applicable in this field.

2. Safety of Working Machines — Testing Standards and Procedures

The safety of work machine cabins is a crucial area of engineering, aimed at protecting the operator under demanding working conditions. All work machines are designed to operate in harsh environments, and when addressing work machine safety, the primary focus is the protection of the operator. Learning from past shortcomings in cabin design and advances in technology, significant progress has been made in adopting improved, safer, more functional, technically advanced, and ergonomically optimized work machine cabins.

The first studies on protective structures date back to the 1970s, culminating in the release of the first version of the ISO 3471 standard in 1980, which specifies laboratory testing and performance requirements for machines to achieve protective structures against overturning. In 1986, the European Economic Community (EEC) published Directives 295 and 296, which mandated the testing of machines for protection against overturning (ROPS) and falling objects (FOPS), originally intended for construction equipment.

Shortly thereafter, in 1989, the Machinery Directive 392 came into force, aiming to unify and establish clear requirements for all machinery within the European Economic Community, including mandatory ROPS/FOPS testing to ensure their safe use.

In 1994, the first version of the EN 474 standard was introduced, setting general safety requirements for earthmoving machinery, particularly in the construction sector.

In 2006, the European Parliament and the Council of the European Union published Machinery Directive 2006/42/EC, which replaced the previous directive and established the fundamental safety requirements for all machinery placed on the European Union market [11]. In the same year, the EN 474 standard was revised [12].

The adoption, implementation, and subsequent revision of these standards have led to the development of working machine constructions that effectively protect operators during workplace accidents, while continuously striving for improvement and reinforcement in every aspect.

The construction and design of the entire machine, as well as its components such as the cabin, primarily depend on the type of working machine and its intended purpose. Consequently, these aspects differ mainly in overall dimensions, protective structures, ergonomics related to long-term machine use, and additional operational features. For this reason, the standards distinguish requirements for machines intended for agriculture [13] from those intended for earthmoving (construction) work [12]. Table 1 shows the classification of agricultural machines, and Table 2 shows that of earthmoving machines according to the corresponding standards.

Table 1. Classification of agricultural machines according to the BAS EN ISO 4254 standard [13].

No.	Standard Section	Machine Type
1.	ISO 4254-5	Self-propelled soil tillage machines
2.	ISO 4254-6	Sprayers and liquid fertilizer spreaders

3.	ISO 4254-7	Combine harvesters, forage harvesters, and cotton pickers
4.	ISO 4254-8	Solid fertilizer spreaders
5.	ISO 4254-9	Seeders
6.	ISO 4254-10	Rotary hay tedders and rakes
7.	ISO 4254-11	Bale balers with collector
8.	ISO 4254-12	Disc and drum rotary mowers and brush mowers
9.	ISO 4254-13	Large rotary mowers

Table 2. Classification of earthmoving machines according to the BAS EN ISO 474 standard [12].

No.	Standard Section	Machine Type
1.	ISO 474-2	Tractor bulldozers
2.	ISO 474-3	Loaders
3.	ISO 474-4	Backhoe loaders
4.	ISO 474-5	Hydraulic excavators
5.	ISO 474-6	Dumpers (dump trucks)
6.	ISO 474-7	Scrapers
7.	ISO 474-8	Graders
8.	ISO 474-9	Pipe layers
9.	ISO 474-10	Excavators
10.	ISO 474-11	Soil and waste compaction rollers
11.	ISO 474-12	Cable-operated excavators

To fully understand the safety of a working machine, it is essential to examine the standards, regulations, and other legal acts that comprehensively define all aspects required to produce a high-quality end product capable of withstanding and absorbing operational stresses.

3. Safety Assessment and Evaluation of Work Cabin Structures

The development of technologies aimed at protecting both people and the environment is grounded in the principle of ensuring safe and reliable working conditions for operators of machines intended for construction or transport purposes. Previous risk monitoring, analyses, and statistical data reveal varying levels of risk associated with operating different types of machinery.

By introducing globally harmonized procedures, equal levels of protection are provided to operators, regardless of the country in which they operate. The purpose of safety status analysis and verification is to assess and control the cabin's ability to protect the operator under extreme working conditions, such as the impact of a falling object on the machine's roof structure—something that should always be considered imperative.

Ensuring the quality of cabin construction begins during manufacturing, which involves inspecting the input materials, monitoring the production process, and conducting a final inspection of the completed structure. In addition to laboratory testing of materials, welds must also be tested—both destructively and non-destructively. Non-destructive testing (NDT) methods are preferred, as they are more environmentally friendly and allow production to continue if the structure meets the required standards. Among the most commonly used destructive and non-destructive weld testing methods are visual inspection, penetrant testing, metallographic testing, and Charpy impact testing.

Two key standards that eliminate technical barriers and ensure quality in welded structures are ISO EN 3834 and EN 1090. Structural failures most often occur in or near welded joints, and weld quality depends directly on the welding process. Verifying weld quality is essential to confirm the reliability of the overall structure.

Dimensional control is also an indispensable method used during the production of working machine cabin structures.

To evaluate cabin safety—particularly in terms of operator protection—two primary test methods are used:

- FOPS (Falling Object Protective Structures)
- ROPS (Rollover Protective Structures).

The FOPS test (Falling Object Protective Structures) is essential for the homologation of operator cabins, as it simulates falling objects and measures roof deformations to verify the level of protection in

scenarios such as landslides or rockfalls—common, for example, in excavator operations. The primary goal is to ensure that the cabin provides effective protection for the operator under extreme working conditions, regardless of geographic location. FOPS testing standards vary depending on the machine type:

- ISO 3449: – for construction machinery (e.g. earthmoving machines)
- OECD Code 10 - for agricultural machinery (both prescribed a 45 kg load.)

Since this study focuses on construction machinery cabins, the test is conducted by the relevant standard by dropping a specified mass from a defined height in free fall. The key parameters evaluated are the impact energy generated and the structural deformations of the cabin.

The test consists of two levels, each using different weights to simulate real-world impact conditions (Figure 1). Level I simulates the fall of a lighter object above the operator's feet—a more frequent scenario in practice. Level II simulates the fall of a heavier object above the operator's head, which represents the most critical structural area in the test. This is because the deflection limiting volume (DLV) in this region is significantly closer to the cabin roof (Figure 2).

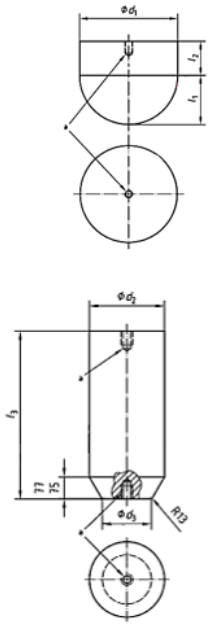

Figure 1. FOPS testing: appearance and dimensions of test objects – Impact I: 45 kg, Impact II: 227 kg.

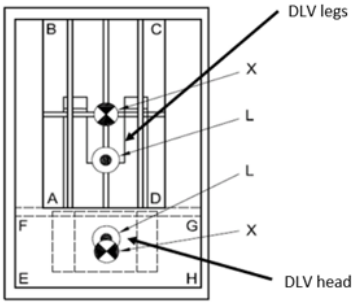

Figure 2. Impact locations of test objects: Impact I – Deflection Limiting Volume (DLV) legs, Impact II – DLV head.

For additional research, sensors can be installed to monitor forces, deformations, and other relevant data during the test. In addition, visual inspection can determine whether the cabin meets the required safety criteria.

Preparation for the FOPS test involves placing the cabin on a platform and securing it at designated points, as well as accurately positioning the weights above the structure. It is essential to ensure the prescribed free-fall distance and achieve the required impact energy.

Figure 3 shows the position of the cabin and the falling object before the test. Once preparations are completed, the test is conducted according to the specified procedure. Figure 4 illustrates the cabin appearance after the second level of testing, specifically following the first impact on the front section of the cabin above the operator's legs (DLV legs).

Figure 3. Preparation for the FOPS test – positioning of the cabin and test object [14].

Figure 4. Deformation of the cabin roof after the second impact [14].

The test is considered successful if the deformation of the cabin structure does not intrude into the operator's safety space, i.e., the Deflection Limiting Volume (DLV). This ensures adequate protection of the operator from falling objects.

ROPS (Rollover Protective Structure) testing using the static method simulates machine overturning by measuring deformations in multiple load directions: lateral, vertical, and longitudinal. The EN ISO 3471:2008 standard defines the procedure, testing conditions, and acceptance criteria for the obtained results. Both construction and agricultural machines are subject to this type of testing, with minor differences in the load sequence and number of applications due to variations in cab design. The test can be performed statically, dynamically, or in the field and is mandatory even for the smallest design modifications or repairs to an existing cabin structure. In addition to the basic standard EN ISO 3471:2008, specific tests for different machine types are prescribed by additional standards:

- ISO 12117-2:2008 – for excavators weighing between 6 and 50 tons; the load is applied in the following sequence: lateral, longitudinal, vertical.
- OECD CODE 4 – for agricultural machines; the load application follows this order: longitudinal, vertical (first), lateral, vertical (second), and an additional longitudinal load for two-post tractors.

For construction and earthmoving machinery, the standard test sequence involves load application in the following order: lateral, vertical, and longitudinal, as illustrated in Figure 5.

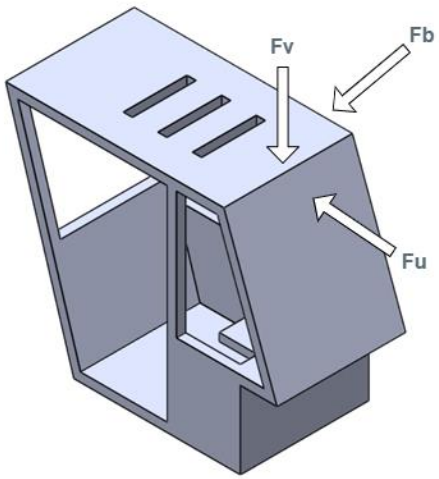

Figure 5. Position and direction of force application during ROPS testing.

The standard defines both the force intensities applied during the test and the required energy absorption under lateral loading, as shown in Table 3.

Table 3. Standard values of forces and absorbed energy in ROPS tests.

Machine mass m (kg)	Lateral load F (N)	Lateral energy U (J)	Vertival load F (N)	Longitudinal load F (N)
700< m ≤4630	6m	$13.000(m/10.000)^{1,25}$		4,8m
4630< m ≤59500	$70.000(m/10.000)^{1,2}$	$13.000(m/10.000)^{1,25}$	19,61m	$56.000(m/10.000)^{1,2}$
m ≥ 59500	10m	2,03m		8m

Sensors are, of course, installed on the cabin before this test, just as in the FOPS test. The first step in ROPS testing involves applying a lateral load to the edge of one of the selected sides, as shown in Figure 6.a), in order to assess the cabin's resistance to lateral forces.

Figure 6. Cabin testing: a) lateral load, b) vertical load [14].

The second step, following the lateral force application, is the application of a vertical load on the cabin roof, to evaluate the strength of the roof structure (Figure 6.b)). Since a rollover may also occur from the rear, the third and final step in the test includes applying a longitudinal force from the rear side of the cabin.

Once the test is completed, all data are documented and analyzed to verify compliance with the defined safety criteria. If the cabin structure remains outside the operator's DLV (Deflection Limiting Volume) and meets all required safety parameters, the design is approved and can be implemented in production.

4. Conclusion

The safety of working machines is a crucial factor in protecting operators, particularly in the event of workplace accidents. This paper, through the analysis of existing standards, testing methods, and practical applications, highlights the essential role of FOPS (Falling Object Protective Structures) and ROPS (Rollover Protective Structures) tests in the verification, certification, and assurance of the strength and functionality of cabin protective structures.

What both test types have in common is that the cabin is subjected to rigorous mechanical testing-including both static and dynamic procedures-supported by sensors and measuring equipment that allow for detailed analysis of results. Only cabins that successfully pass these tests can be homologated and approved for use, thereby guaranteeing their reliability under extreme operating conditions.

Destructive and non-destructive testing methods enable early detection of potential structural defects and allow for timely corrections and design optimization. The integration of FOPS and ROPS testing with numerical simulations and modern non-destructive techniques provides manufacturers with the tools to identify weaknesses early in the development process, ultimately leading to enhanced safety standards.

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Experimental testing and comparative analysis of fracture mechanics parameters of welded sheet steel joints of new and old material

Fadil Islamović*, Ermin Bajramović, Belma Islamović-Čavkić and Esad Bajramović

Faculty of Technical Engineering, University of Bihać, Bihać, Bosnia and Herzegovina

*E-mail: fadil.islamovic@unbi.ba

Abstract. The repair process of war-ravaged vertical cylindrical tanks with 5.000 m^3 volume located at the TTT S-105 Ribić liquid cargo oil terminal in Bihać included previous experimental check of the fracture mechanics parameters of welded steel sheet joints, in addition to other tests. A new steel sheet of quality Č.0361 was purchased for these purposes, but a sample of an old sheet of the same quality was also taken from the construction of the devastated tank, which had been in use for more than 30 years. Through experimental testing, it was necessary to determine the values of the fracture mechanics parameters of the new material, to examine the same parameters of the old, already used material, to compare the obtained results, and to confirm their mutual acceptability in the joint construction. The tank in question was devastated as a result of direct or indirect hits by artillery projectiles during the war period, and after the completion of the economically acceptable repair that is in progress, compared to demolition and complete reconstruction, it should be returned to a safe and usable condition.

1. Introduction

The storage oil terminal (Liquid cargo terminal TTT S-105 Ribić) in Bihać is one of the four oil terminals in the territory of the Federation of Bosnia and Herzegovina managed by the Operator - Terminali Federation, d.o.o. Sarajevo. The total capacity for storage of oil derivatives in five vertical above-ground cylindrical tanks with a fixed roof of this terminal is 18.100 m3. In relation to the total storage capacity of the company Terminali Federacije, d.o.o. Sarajevo, this terminal in Bihać occupies about 10% of capacity. Technical data on capacities, dimensions, and types of storage derivatives for which individual tanks are intended are given in Table 1 [1].

Table 1. Technical data of vertical cylindrical tanks for storage of petroleum products [1].

Tank	Capacity (m^3)	Diameter (m)	Type of derivative
R-01	2.700	20	Diesel
R-02	2.700	20	Diesel
R-03	5.000	24	Petrol
R-04	5.000	24	Diesel
R-05	2.700	20	Fuel oil

One of the two tanks of this terminal with a 5.000 m^3 volume, which is intended for the storage of diesel fuel, was damaged by direct and indirect projectiles during the war, as shown in Figure 1. The damage to the tank's cylindrical shell is marked in Figure 1, as well as the place where the old material was cut to create the test tubes that will be used in the experimental testing. The experimental testing should determine the values of the fracture mechanics parameters of the new material, examine the same parameters of the old, already used material, compare the obtained results, and confirm their mutual acceptability in the joint construction.

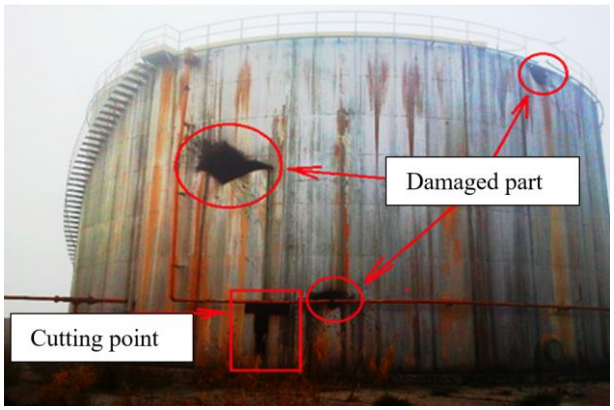

Figure 1. A devastated vertical cylindrical 5.000 m³ volume tank [2].

Comprehensively performed experimental tests of mechanical and operational properties of newly purchased and old material sampled from the tank, presented in the paper [1], cover a much wider area of research of a smaller part of the results that will be presented in this paper due to the limited number of pages of the publication. The paper will present the obtained results of the fracture mechanics parameters of the new and old material: critical stress intensity factor (K_{Ic}), critical J-integral (J_{Ic}) and critical crack length (a_c), and how these results affect the evaluation of the integrity and remaining life of the structure after the restoration of the tank and putting it back in service.

2. Determination of fracture toughness during plane strain K_{Ic}

The fracture toughness at plane strain of test tubes sampled from welded plates of steel Č.0361 was conducted in order to determine the critical stress intensity factor, K_{Ic}, i.e. the evaluation of the behavior of the base metal and welded joint components, the weld metal (WM) and the heat affected zone (HAZ) in the presence of a crack-type defect, as the most dangerous of all defects in structural materials, especially welded joints of structures. The test was performed on a welded joint of new material, as well as on a welded joint of old material extracted from a devastated vertical tank with a flat bottom located at the terminal in Bihać. The three-point bending test tubes (SEB test tubes) were used for testing, the geometry of which is defined by the ASTM E399 standard and is given in Figure. 2. The three-point bending test tube (SEB test tube) has proven to be very suitable for practice, and is therefore the most widely used [3].

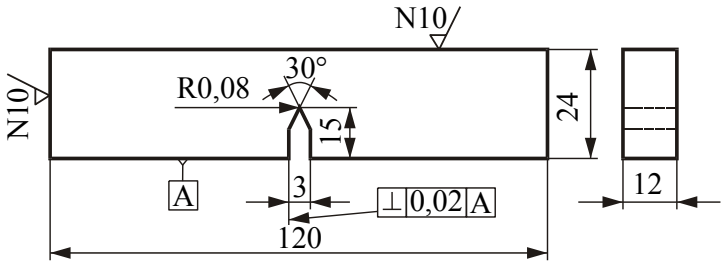

Figure 2. Test tube SEB for fracture mechanics testing [3].

Three groups of test tubes were created depending on the place where the notch was made, namely:

- Group I – test tubes with notch in the base metal (BM),
- Group II – test tubes with notch in the weld metal (WZ), and
- Group III – test tubes with notch in the heat-affected zone (HAZ).

For the welded joint of new material, test tubes with notch in the WM were tested, where the EVB 50 electrode was used as the additional material, and VAC 60 wire was used as the additional material, as well as test tubes with notch in the HAZ for all four selected welding technologies (A, B, C and D): technology A - REL procedure with the EVB 50 electrode without preheating; technology B - REL procedure with the EVB 50 electrode with preheating; technology C - MAG procedure with the VAC 60 wire without preheating;

technology D - MAG procedure with the VAC 60 wire with preheating. Test tubes with notch in the WM and HAZ were tested for the welded joint of old material [4].

As defined by the ASTM E399 standard [3], the first step was to prepare the test tube, that is, to create a fatigue crack on the test tubes for three-point bending. A fatigue crack is necessary in order to create the conditions of plane strain, because the desired stress field can be achieved around the tip of the fatigue crack in a reproducible way, on the condition that the fatigue crack provided the appropriate conditions. The creation of the fatigue crack was performed on the high-frequency pulsator ''AMSLER'' (Figure 3). This device can realize a sinusoidal unidirectional variable load in the range of -100 to 100 kN. Medium load and load amplitude was registered with an accuracy of ±50 N. The achieved frequency ranged from 90 to 100 Hz, which is directly dependent on the level of medium load and load amplitude.

Since the requirements for the fulfillment of the conditions of a plane strain were not met, instead of applying the linear-elastic fracture mechanics defined by the ASTM E399 standard [3], the elastic-plastic fracture mechanics defined by the ASTM E813 [5], ASTM E1152 [6], ASTM E1820 [7] and BS 7448 [8] standards were used. The goal of using elastic-plastic fracture mechanics is to determine the value of the critical stress intensity factor, K_{Ic}, indirectly through the critical J integral, J_{Ic}, that is, to monitor the crack development under conditions of marked plasticity.

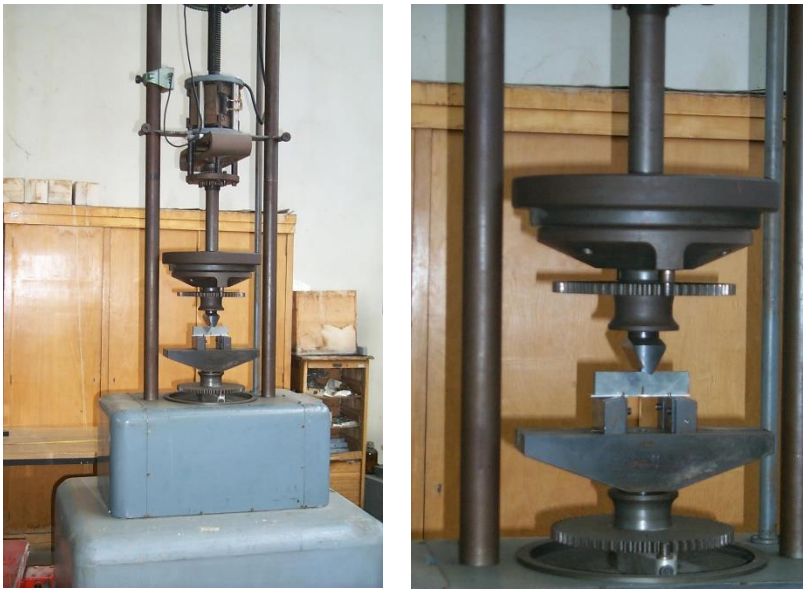

Figure 3. High-frequency system AMSLER [4].

The behavior of an elastic-plastic material, including general structural steel Č.0361, can be described by the J-Δa diagram during stable crack growth, where Δa represents the crack growth, as shown in Figure 4. As the brittle behavior of the material causes the fracture to develop without additional energy consumption, for this case the J-Δa diagram represents a horizontal straight line that intersects the ordinate at the height J_{Ic}. This height corresponds to the critical energy consumption required for the initiation of crack development. When the material behaves plastically, in the initial phase of increasing force and energy consumption, the strain is manifested only by the opening of the existing crack, but not by the growth of the crack. This corresponds to a very steep line of dependence J-Δa, and represents the blunting phase of the crack tip. A change in the slope of the dependence curve happens at the critical point, which means that the further crack opening is related to the growth of the crack and the increase in its length. The inflection point in the initial phase is taken as J_{Ic}, and based on this value, the critical stress intensity factor K_{Ic} can be determined [4].

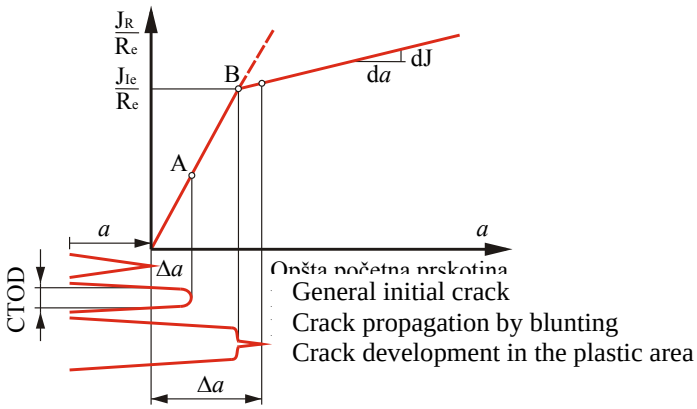

Figure 4. Schematic representation of J-Δ dependence during stable crack development [4].

The American Society for Testing Materials (ASTM) has established a standard procedure for obtaining resistance curves of metallic materials according to crack development. The improvement of this standard was carried out within the framework of the European Society for the Integrity and Life of Structures ESIS [9]. These standards are regularly supplemented based on research in which these standards are applied [10, 11], and therefore it is important to take care that the latest versions of the standards are applied.

Therefore, the aim of this experiment is to determine the critical value of the J integral, J_{Ic}. The test procedure is reflected in obtaining the R-curve, that is, the J-Δa curve, which consists of the value of the J integral for uniform crack growth Δa. The experiments were carried out using the method of testing one test tube with successive partial unloading, that is, the yielding method of one test tube, as defined by the ASTM E1152 standard [6]. The aim of the yield stress method is to register the size of the crack development, Δa, which occurs during the test.

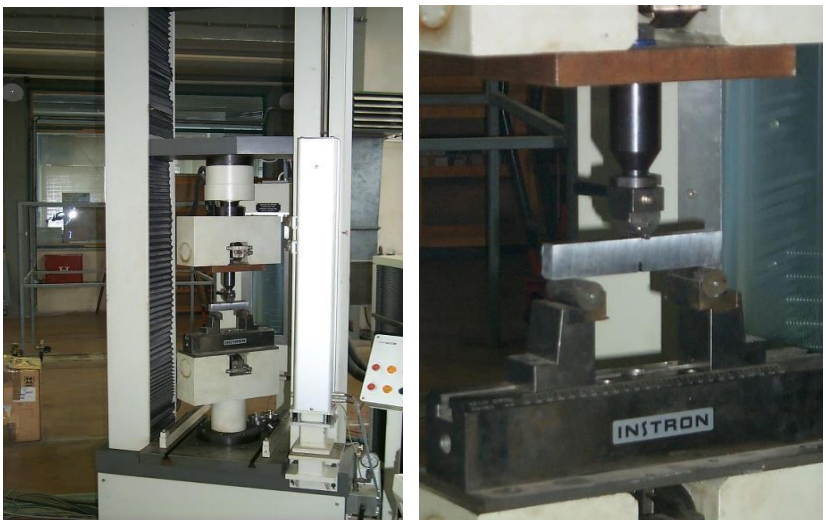

Figure 5. Electromechanical universal testing machine SCHENCK-TREBEL RM 400 [4].

The test was performed at room temperature on an electromechanical universal testing machine SCHENCK TREBEL RM 400, shown in Figure 5. The test tube equipped with the COD extensometer is placed on the three-point bending tool. The bending load is introduced at low speed. In this case, the load introduction speed was 0.2 mm/min, so that the testing of one test tube lasted about 20 minutes on average. The load is introduced with occasional reliefs until the moment of large plastic strains or fracture of the test tube, i.e. exiting the extensometer measurement range. During this time, the A/D converter collects data on load, displacement (deflection) and crack tip opening [4].

3. Testing of welded joint of a new material

Based on the data collected from the universal testing machine and COD transducer, diagrams force F - crack mouth opening δ (CMOD) were constructed. The designation CMOD is an abbreviation for Crack Mouth Opening Displacement which translates as crack tip opening. The layout of the F- δ diagram is given representatively, namely for a test tube with notch in the base metal (BM) shown in Figure 6, for a test tube with notch in the weld metal (WM) where the EVB 50 electrode was used as an additional material shown in Figure 7, and for a test tube with notch in the heat affected zone (HAZ) with welding technology B - REL procedure with the EVB 50 electrode with preheating shown in Figure 8. The layout of the diagram itself shows the influence of structural heterogeneity on the toughness properties of the base metal and components of the welded joint [4].

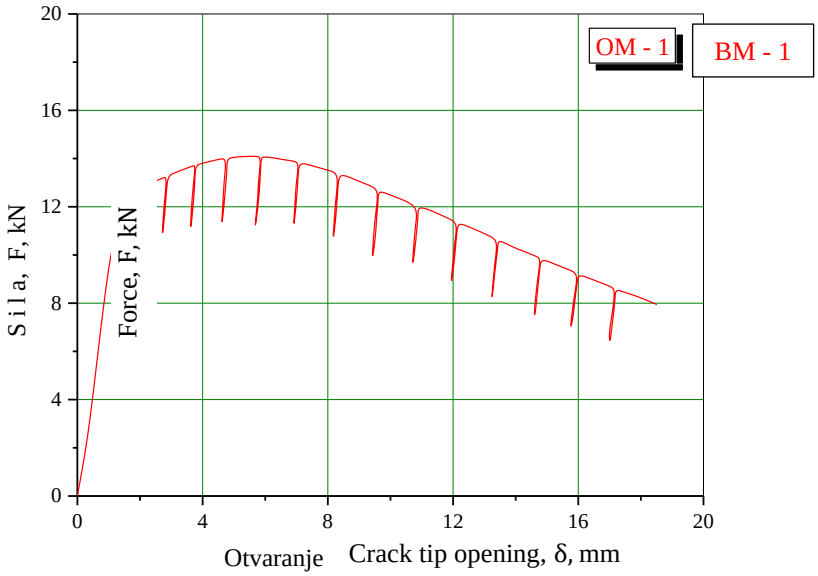

Figure 6. Diagram F - δ of test test tube with notch in BM.

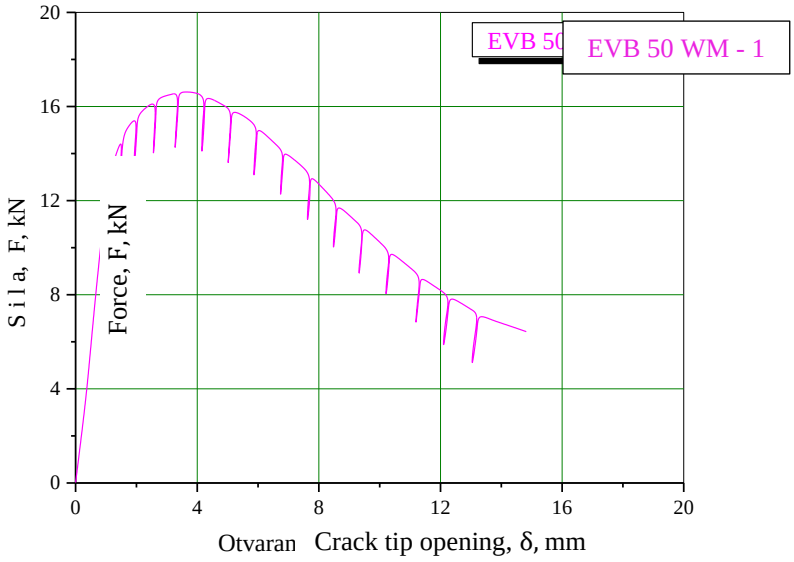

Figure 7. Diagram F - δ of test tube with notch in WM - electrode EVB 50.

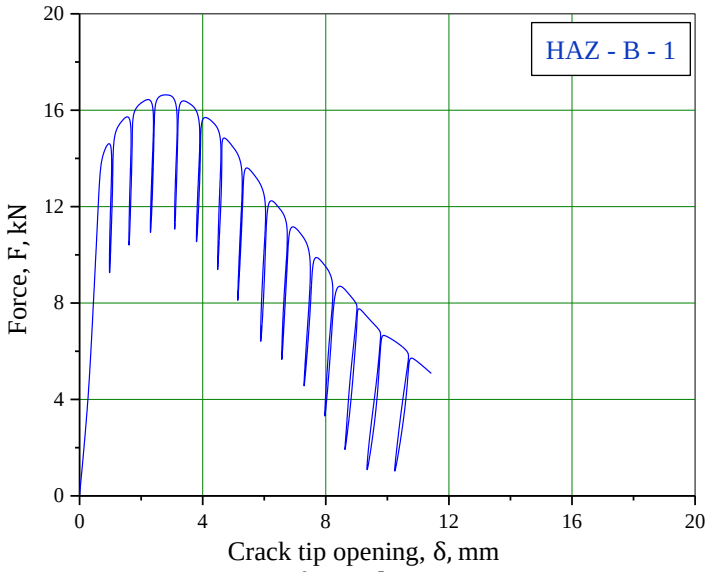

Figure 8. Diagram F - δ of test tube with notch in HAZ - Technology B.

At the end of the testing, the position of the crack caused by test tube bending is marked. Marking the position of the crack is performed by fatigue or heat treatment of the test tube. This must be done in order to determine the total length of the crack more precisely. The tubes are then broken, so that the initial a0 and final crack lengths af can be measured. Given that the crack front is not parallel to the entrance edge of the test tube, measurements are made along 5 to 9 parallel measuring lines, depending on the thickness of the test tube and the regularity of the fatigue crack front [4].

Crack lengths were measured using a special microscope with a reticle along 5 parallel lines. The scheme of the crack length measurement procedure is given in Figure 9, while the layout of the crack measurement with a special microscope is given in Figure 10 [4].

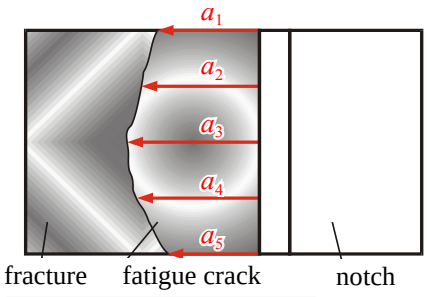

Figure 9. Scheme of the measurement procedure of crack length.

Figure 10. Measuring crack length with a special microscope.

Fatigue crack length is: $$a_Z = \frac{a_{z1} + a_{z2} + \ldots a_{zn}}{n} \quad (1)$$

Total crack length is: $$a = a_O + a_Z \quad (2)$$

The measured crack lengths at 5 measuring points with the mean value are given in Table 2 for test tubes with notch in BM and WM, and in Table 3 for test tubes with notch in HAZ for all four selected welding technologies (A, B, C, D) [4].

Table 2. Results of crack length measurements of test tubes with notch in BM and WM.

Placement of notch	Test tube mark	Crack length, a, (mm)					Mean value, a_{sr}, (mm)
		a_1	a_2	a_3	a_4	a_5	
BM	BM-1	4.21	5.17	6.03	5.26	4.26	4.99
	BM-2	4.72	5.52	6.35	5.73	4.65	5.39
	BM-3	4.58	5.31	6.03	5.2	4.46	5.12
WM - EVB 50	WM-1	3.63	4.91	6.11	6.94	3.33	4.98
	WM-2	4.02	5.45	6.68	5.4	3.98	5.11
	WM-3	4.08	5.2	6.38	5.21	4.11	5.00
WM - VAC 60	WM-1	3.70	5.01	6.32	5.05	3.79	4.77
	WM-2	3.97	5.29	6.52	5.23	3.9	4.98
	WM-3	4.05	5.32	6.65	5.39	4.16	5.11

Table 3. Results of crack length measurements of test tubes with notch in HAZ.

Selected welding technology	Test tube mark	Crack length, a, (mm)					Mean value a_{sr}, (mm)
		a_1	a_2	a_3	a_4	a_5	
HAZ - A	A-1	4.22	5.49	6.81	5.43	4.17	5.22
	A-2	4.65	5.83	6.02	5.92	4.71	5.43
	A-3	4.51	5.75	6.09	5.72	4.48	5.31
HAZ - B	B-1	3.85	5.02	6.24	5.07	3.9	4.82
	B-2	4.04	5.28	6.46	5.32	4.11	5.04
	B-3	4.12	5.32	6.53	5.37	4.22	5.11
HAZ- C	C-1	4.07	5.26	6.43	5.29	4.12	5.03
	C-2	4.20	5.42	6.61	5.45	4.22	5.18
	C-3	4.37	5.56	6.72	5.50	4.31	5.29
HAZ - D	D-1	3.75	4.81	5.87	4.89	3.82	4.63
	D-2	4.32	5.43	6.18	5.26	4.12	5.06
	D-3	4.07	4.87	5.65	4.94	4.21	4.75

Noticeable reliefs on the curve force F - crack tip opening δ are used to determine the compliance of the test tube for three-point bending at the current crack length *a*. Based on yield value, which is represented by the ratio of increment δ and increment F on the relief line, it is possible to determine the crack by using the expression:

$$\Delta a_i = \Delta a_{i-1} + \left(\frac{b_{i-1}}{2}\right) \cdot \left(\frac{C_{i-1} - C_i}{C_i}\right) \tag{3}$$

Where:
a_{i-1} - previous crack length.
$C_i = tg\alpha_i$ - slope of the observed relief line.
$C_{i-1} = tg\alpha_{i-1}$ - slope of the previous relief line.

Integral J is equal to the sum of elastic component of J integral and plastic component of J integral:

$$J = J_{el} + J_{pl} \tag{4}$$

Elastic component of J-integral, i.e. energy, is calculated based on expression:

$$J_{el(i)} = \frac{K_i^2 \cdot \left(1 - \nu^2\right)}{E} \tag{5}$$

Where:
K_i - stress intensity factor, defined by standard ASTM E 399-89 [3],
υ - Poisson's ratio and
E - Young's modulus.

Stress intensity factor is calculated based on expression:

$$K_i = \frac{F_i \cdot S}{\left(B \cdot B_N\right)^{1/2} \cdot W^{3/2}} \cdot f\left(a_0/W\right) \tag{6}$$

The value of expression f (a_0/W) is calculated based on equation:

$$f\left(a_0/W\right) = \frac{3\left(a_0/W\right)^{1/2}\left[1.99 - \left(a_0/W\right)\left(1 - a_0/W\right)\left(2.15 - 3.93\left(a_0/W\right) + 2.7\left(a_0/W\right)^2\right)\right]}{2\left(1 + 2a_0/W\right)\left(1 - a_0/W\right)^{3/2}} \tag{7}$$

Plastic component of J-integral, i.e. energy, is calculated based on equation:

$$J_{pl(i)} = \frac{2 \cdot A_{pl}}{B_N \cdot b_i} \tag{8}$$

Where:
A_{pl} - plastic energy component, Figure 11,
B_N - net width of test tube, in this case BN = B because test tube was not created with side notches.

J integral is calculated based on dependence:

$$J_i = \left[J_{i-1} + \left(\frac{2}{b}\right) \cdot \frac{A_i - A_{i-1}}{B}\right] \cdot \left[1 - \frac{a_i - a_{i-1}}{b_i}\right] \tag{9}$$

Where:
A - area under the curve,
B - test tube thickness,
b - ligament length.

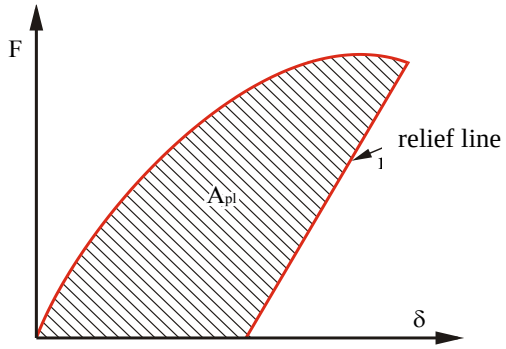

Figure 11. Plastic energy component [4].

Based on the obtained data, J - Δa curve is created, on which a regression line is constructed according to ASTM E813 [5]. The critical J integral, J_{Ic} is acquired from the obtained regression line.

Typical example of curve J - Δa obtained by testing test tubes with notch [4]:
- in base metal (BM) is given in Figure 12,
- in weld metal (WM) is given in Figure 13 for additional material EVB 50, and
- in heat affected zone (HAZ) for selected B welding technology is given in Figure 14.

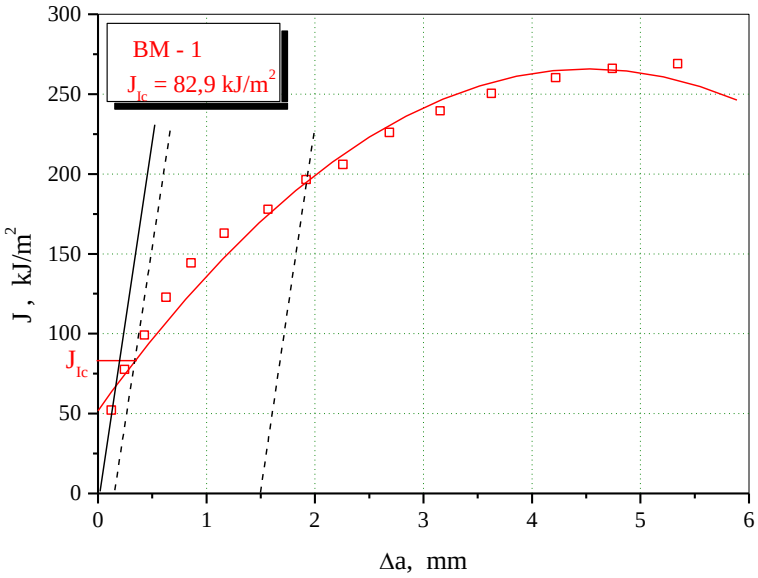

Figure 12. Diagram J - Δa of test tube in BM - 1.

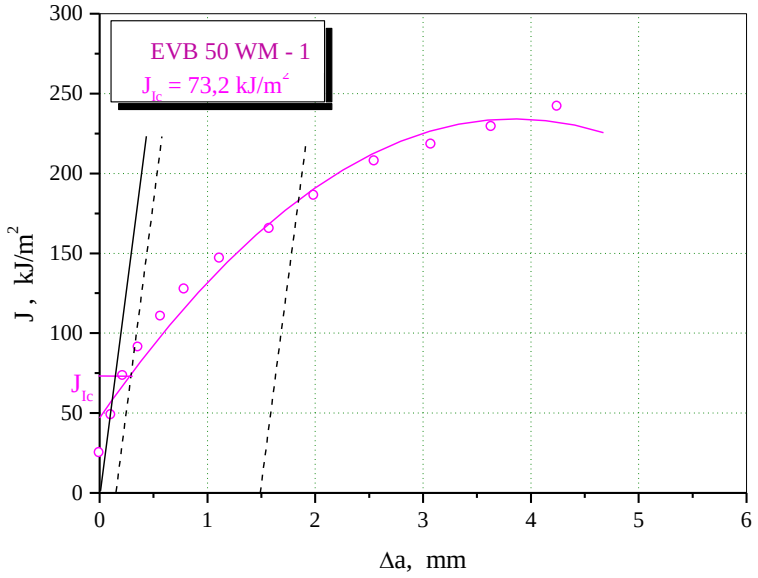

Figure 13. Diagram J - Δa of test tube in WM - 1 (additional material EVB 50).

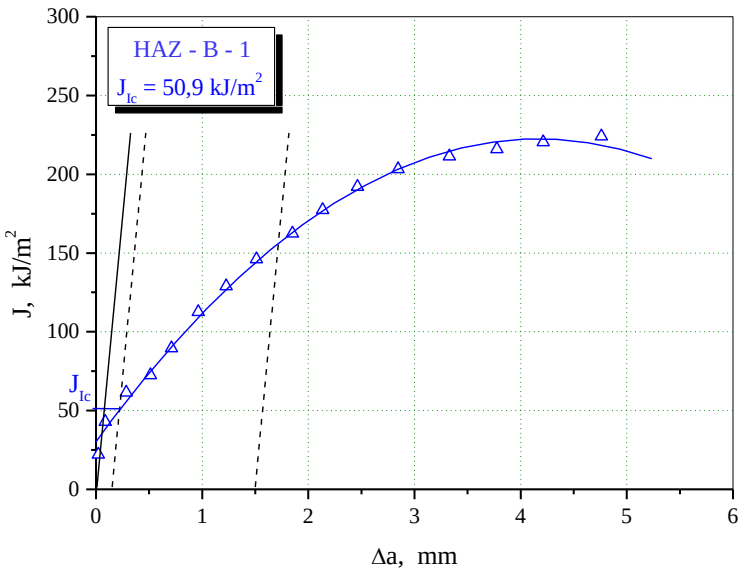

Figure 14. Diagram J - Δa of test tube in HAZ - B - 1 (Technology B).

Knowing the values of the critical J_{Ic} integral can help calculate the value of the critical stress intensity factor or fracture toughness at plane strain, K_{Ic}, using the dependence:

$$K_{Ic} = \sqrt{\frac{J_{Ic} \cdot E}{1-\nu^2}} \tag{10}$$

The calculated values of the fracture toughness under plane strain, K_{Ic}, are given in Table 4 for test tubes with notch in the BM, in Table 5 for test tubes with notch in the WM, and in Table 6 for test tubes with notch in the HAZ [4].

Table 4. Values of fracture mechanics parameters for test tubes with notch in BM.

Test tube mark	Critical J-integral, J_{Ic}, (kJ/m²)	Critical stress intensity factor, K_{Ic}, (MPa m$^{1/2}$)
BM - 1	83.1	138.5
BM - 2	79.3	135.3
BM - 3	80.0	135.9
Mean value	80.8	136.6
Standard deviation	2.022	1.701

Table 5. Values of fracture mechanics parameters for test tubes with notch in WM.

Test tube mark	Used electrode	Critical J-integral J_{Ic}, (kJ/m²)	Critical stress intensity factor, K_{Ic}, (MPa m$^{1/2}$)
WM - A - 1		73.2	128.4
WM - A - 2	EVB 50	71.7	127.1
WM - A - 3		69.5	125.1
Mean value		71.5	126.9
Standard deviation		1.861	1.66233
WM - C - 1		57.8	113.6
WM - C - 2	VAC 60	57.0	112.8
WM - C - 3		61.4	117.0
Mean value		58.7	114.5
Standard deviation		2.3438	2.2301

Table 6. Values of fracture mechanics parameters for test tubes with notch in HAZ.

Test tube mark	Welding technology	Critical J-integral J_{Ic}, (kJ/m^2)	Critical stress intensity factor, K_{Ic}, (MPa m$^{1/2}$)
HAZ - A - 1		45.1	100.1
HAZ - A - 2	A	47.3	102.5
HAZ - A - 3		45.8	100.8
Mean value		46.1	101.1
Standard deviation		1.124	1.23423
HAZ - B - 1		50.9	107.6
HAZ - B - 2	B	53.9	110.7
HAZ - B - 3		57.8	114.7
Mean value		54.2	111.0
Standard deviation		3.460	3.5595
HAZ - C - 1		33.1	85.1
HAZ - C - 2	C	34.7	87.1
HAZ - C - 3		37.5	90.6
Mean value		35.1	87.6
Standard deviation		2.227	2.7839
HAZ - D - 1		39.5	93.4
HAZ - D - 2	D	42.3	96.7
HAZ - D - 3		40.7	94.8
Mean value		40.8	95.0
Standard deviation		1.405	1.6563

It is noticeable that the structural and mechanical heterogeneities of the welded joint have a significant impact on its resistance to crack development, both in the elastic and in the plastic area. For this reason, it is necessary to define not only the test procedure and the position of the fatigue crack, but also the method of interpretation and the meaning of the results when prescribing the conditions for fracture mechanics testing.

The heterogeneity of the mechanical properties of the welded joint, i.e., the components of the welded joint, can be clearly seen through the obtained values of the fracture toughness at plane strain, K_{Ic}, determined indirectly through the critical J_{Ic} integral. Test tubes with a notch in the base metal have the highest measured value of K_{Ic}. The obtained K_{Ic} values of an average of 136.6 MPa m$^{1/2}$ are within the limits of literature values for this group of general structural steels.

Slightly lower K_{Ic} values are found in test tubes with a notch in the WM, of which the additional material EVB 50 (mean K_{Ic} value is 126.9 MPa m$^{1/2}$) shows higher fracture resistance than the additional material VAC 60 (mean K_{Ic} value is 114.5 MPa m$^{1/2}$). However, in this specific case, the differences are relatively small and range from approximately 10-15 MPa m$^{1/2}$ in relation to the minimum and maximum values.

The lowest values are found in HAZ, which normally represents a critical point in the welded joint. However, introducing heat into the base metal, i.e. preheating, has a positive effect on increasing the resistance to fracture. Technology B (mean value of K_{Ic} is 111.0 MPa m$^{1/2}$), where the EVB 50 electrode with previous preheating was used as an additional material, shows the best resistance to fracture, i.e. in this case the best K_{Ic} values were obtained.

These differences do not have to have a significant impact on constructions that are exposed to static load during operation. However, if it is a question of conditions where structural elements are exposed to a constant variable load, changes in the K_{Ic} value are very significant because the critical crack length ac, i.e. resistance to crack propagation, directly depends on the K_{Ic} value.

The character of the curves only changes depending on the place where the notch is placed, that is, the place where the fatigue crack penetrated. Analyzing the obtained curves, an almost identical dependence of the character of the individual curves in each group is visible, with the fact that the difference between the test tubes exists in the value of the maximum force, F_{max}, which is directly dependent on the length of the fatigue crack a.

It should be noted that from the construction aspect, the properties of the material can be much better assessed through the individual values of the sizes K_{Ic} and $R_{p0,2}$ and their relationship (which is also the relevant size in the ASTM E399, i.e. BS 7448 standard), than only on the basis of one of them.

By applying the basic fracture mechanics formula:

$$K_{Ic} = \sigma \cdot \sqrt{\pi \cdot a_c} \tag{11}$$

and entering the value of the conventional yield stress $R_{p0,2} = \sigma$, assuming that the shape factor is equal to one, approximate values for the critical crack length, ac, can be calculated.

It is obvious that the allowable stress, which is lower than the conventional yield stress, will give higher values for the critical crack length. This means that the tested welded joint, that is, the components of the welded joint, can have cracks up to the specified lengths during operation, without the risk of brittle fracture. For this reason, and in order to reliably detect the crack before it reaches a critical length, suitable non-destructive testing procedures should be used. It is important to note that the calculated values of the critical length of the crack, ac, refer to the conditions of plane strain, and that for each specific case it must be corrected in relation to the actual thickness of the construction material.

4. Testing of welded joints of old material

Determining the fracture toughness during plane strain, K_{Ic}, by testing test tubes extracted from butt-welded joints from the devastated tank with 5,000 m3 volume, located at the terminal in Bihać, was also performed according to ASTM E399, ASTM E813, ASTM E1152, ASTM E1820 and BS 7448 standards. Three-point bending test tubes (SEB) were used for testing, whose geometry was defined by the ASTM E399 standard. Three groups of test tubes were made depending on the place where the incision was made, namely:

- Group I – test tubes with notch in the base metal (BM),
- Group II – test tubes with notch in the weld metal (WM), and
- Group III – test tubes with notch in the heat-affected zone (HAZ).

The test tube preparation procedure, as well as the testing, the processing of the test results, and the interpretation of the results is completely identical to the testing of the butt-welded joint of the new material.

Based on the data collected from the universal testing machine and COD transducer, force diagrams F - crack tip opening δ (CMOD) were constructed. The appearance of the F- δ diagram for a test tube with notch in the base metal (BM) is given in Figure 15, for a test tube with notch in the weld metal (WM) in Figure 16, and for a test tube with notch in the heat affected zone (HAZ) in Figure 17. Here too, the appearance of the diagram shows the influence of structural heterogeneity on the toughness properties of the base metal and components of the welded joint [4].

After the test is completed, the crack tip formed by bending the test tube is marked. Next, the test tubes are broken, so that the initial a_0 and final crack lengths af can be measured. The measurement of the crack lengths was also carried out with a special microscope with a reticle along 5 parallel lines.

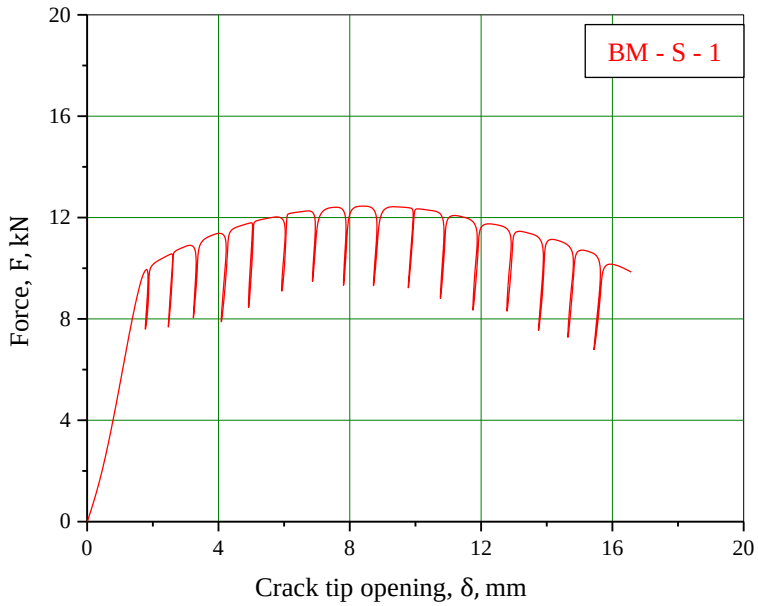

Figure 15. Diagram F - δ of test tube with notch in BM - S - 1.

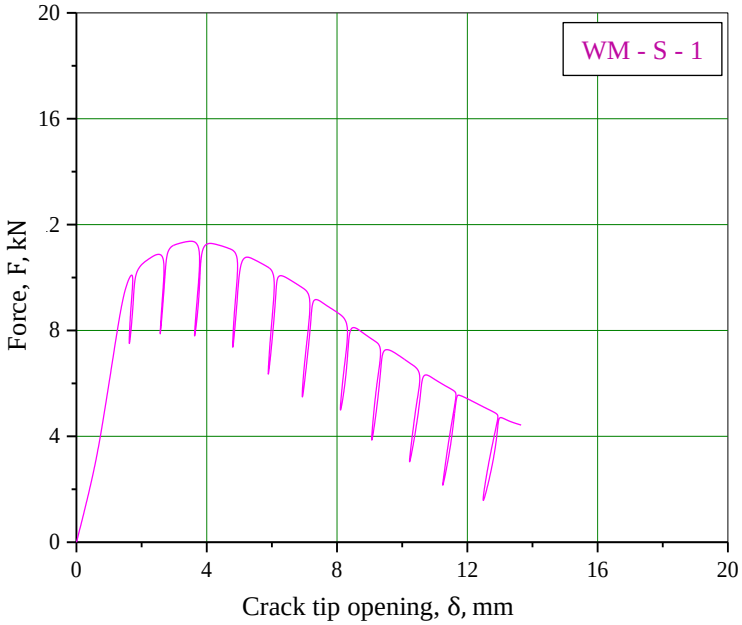

Figure 16. Diagram F - δ of test tube with notch in WM - S - 1.

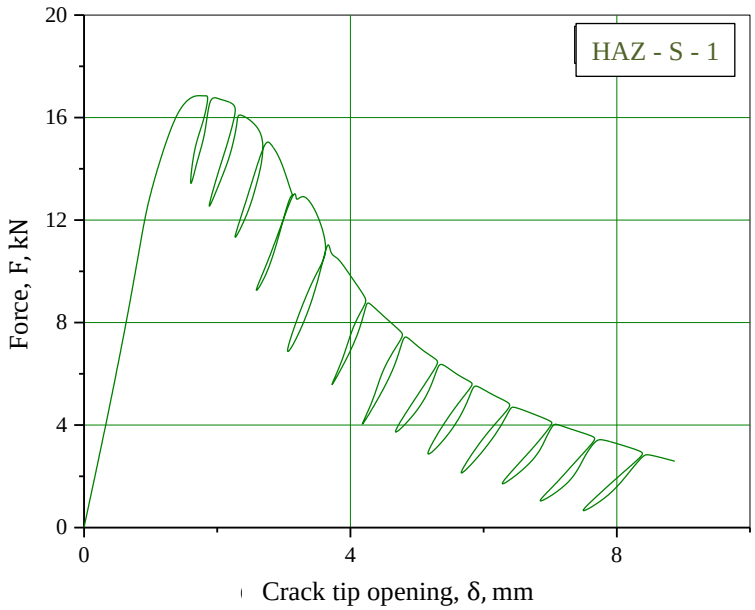

Figure 17. Diagram F - δ of test tube with notch in HAZ - S - 1.

The measured crack lengths at 5 measurement points with the mean value for the test tubes extracted from the welded joint of the old material with notch in BM, WM and HAZ are given in Table 7.

Table 7. Results of crack length measurement of test tubes with notch in BM, WM and HAZ.

Notch placement	Test tube mark	Crack length, a, (mm)					Mean value a_{sr}, (mm)
BM	OM - S - 1	4.36	5.21	6.12	5.30	4.41	5.08
	OM - S - 2	4.18	5.02	6.01	5.11	4.19	4.90
	OM - S - 3	4.24	5.11	6.06	5.09	4.29	4.96
WM	MZ - S - 1	4.46	5.38	6.26	5.41	4.52	5.21
	MZ - S - 2	4.31	5.27	6.12	5.30	4.35	5.07
	MZ - S - 3	4.09	5.04	6.02	5.09	4.11	4.87
HAZ	ZUT - S - 1	3.68	4.67	5.52	4.49	3.45	4.36
	ZUT - S - 2	3.85	4.72	5.56	4.79	3.95	4.57
	ZUT - S - 3	4.06	5.02	5.86	5.12	4.14	4.84

J - Δa curve is constructed based on the obtained data, on which a regression line is constructed according to ASTM E813. The critical J integral, J_{Ic}, is obtained from the acquired regression line. A typical example of the J - Δa curve obtained by testing test tubes with notch [4]:

- in the base metal (BM) is given in Figure 18,
- in the weld metal (WM) in Figure 19, and
- in the heat affected zone (HAZ) in Figure 20.

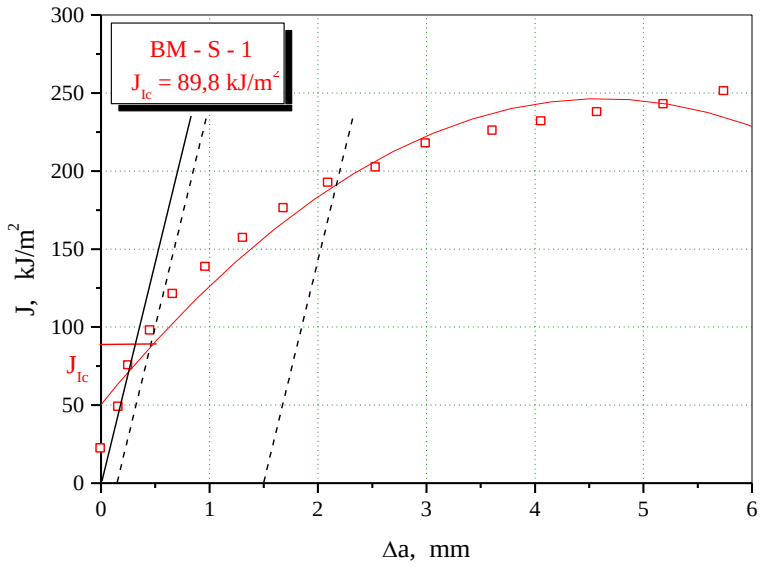

Figure 18. Diagram J - Δa of test tube in BM - S - 1.

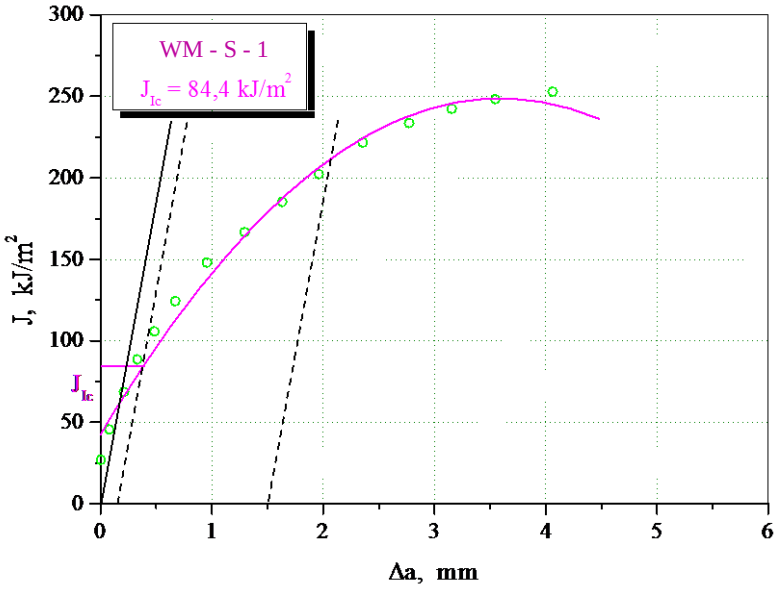

Figure 19. Diagram J - Δa of test tube in WM - S - 1.

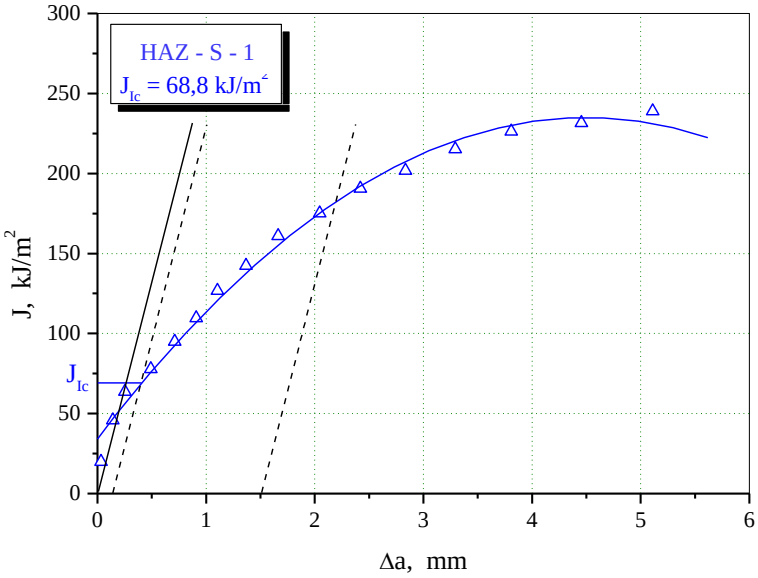

Figure 20. Diagram J - Δa of test tube in HAZ - S - 1.

Knowing the values of the critical J_{Ic} integral enables the calculation of the values of the critical stress intensity factor or fracture toughness at plane strain, K_{Ic}, using dependence (10). The calculated values of fracture toughness during plane strain, K_{Ic}, are given in Table 8 for test tubes with notch in BM, WM, and HAZ [4].

Table 8. Values of the fracture mechanics parameters of the test tubes of the old welded joint.

Test tube mark	Critical J-integral, J_{Ic}, (kJ/m²)	Critical stress intensity factor, K_{Ic}, (MPa m$^{1/2}$)
BM - S - 1	89.8	144.0
BM - S - 2	85.6	140.5
BM - S - 3	87.2	141.9
Mean value	87.5	142.1
Standard deviation	2.120	1.7616
WM - S - 1	84.4	137.9
WM - S - 2	80.7	134.8
WM - S - 3	78.3	132.8
Mean value	81.1	135.2
Standard deviation	3.073	2.5697
HAZ - S - 1	68.8	123.3
HAZ - S - 2	64.9	119.7
HAZ - S - 3	70.3	124.6
Mean value	68.0	122.5
Standard deviation	2.787	2.5384

Even with the components of the old welded joint, structural and mechanical heterogeneities of the welded joint have a significant impact on its resistance to crack development. Somewhat higher values of fracture toughness were obtained at plane strain K_{Ic} in all three groups of test tubes. Test tubes with notch in the base metal have the highest measured value of K_{Ic}, whereas HAZ which normally represents a critical point in the welded joint has the poorest values. A noticeable difference of about 10% can be attributed to a well-defined and executed welding procedure.

In general, the obtained results of fracture mechanics parameter tests: critical stress intensity factor (K_{Ic}), critical J-integral (J_{Ic}) and critical crack length (a_c) indicate two things:

1. First, that the selected welding technology, the REL procedure with preheating (B technology), gave the best results, that is, that the highest values of the fracture mechanics parameters were obtained.
2. Second, the obtained test results of the old material and the welded joint indicate a fairly good condition of both the basic material and the components of the welded joint, regardless of the time of exploitation.

Namely, despite the fact that the exploitation time is over 30 years, the quality of the welded joint in terms of resistance to crack development is quite good, which enables, with the high-quality restoration of damaged parts of the tank and application of welding technology that has shown the best results (B technology), an uninterrupted exploitation period of at least another 20 years.

It goes without saying that all of this applies with mandatory compliance with the regulations on the control of pressure vessels during exploitation.

7. Conclusion

The structural and mechanical heterogeneities of the welded joint of the new material have a significant impact on the resistance to crack development, both in the elastic and in the plastic area. The heterogeneity of the mechanical properties of the welded joint, i.e. the components of the welded joint, can be clearly seen through the obtained values of the fracture toughness at plane strain, K_{Ic}, determined indirectly through the critical J_{Ic} integral:

- test tubes with notch in the base metal (BM) have the highest measured value of K_{Ic},
- additional material EVB 50 shows greater resistance to fracture than additional material VAC 60,
- HAZ has the poorest values, which normally represents a critical point in the welded joint.

However, since the chosen welding technology - B technology (REL procedure with EVB 50 electrode with preheating) demonstrates the best resistance to fracture, the best K_{Ic} values were obtained in this case.

As for the testing of the welded joint of the old material, i.e. samples extracted from the devastated vertical cylindrical tank with a flat bottom and 5.000 m^3 capacity, located at the terminal in Bihać, almost identical dependencies are obtained as in the testing of the new material, from which it can be concluded that the exploitation period of over 30 years had no significant impact on the properties of the material and the welded joint.

This information is very important from the aspect of evaluating the usability and the remaining life of the existing working tanks, as well as the possible rehabilitation of devastated tanks. By comparing the obtained test results of new and old materials, their mutual acceptability in the joint construction was confirmed. In addition, these data support the economic justification of partial reconstruction (which is in progress) in relation to the demolition and construction of completely new tanks.

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Application of Dimensionless Analysis in the Quenching of a Two-Dimensional Axisymmetric Sample

Šefik Behrem* and Bahrudin Hrnjica

University of Bihac, Technical Faculty Bihac

E-mail*: sefik.behrem@unbi.ba

Abstract. In modern scientific and engineering practice, several methods exist for solving partial differential equations, among which analytical and numerical methods are most prominent. This paper applies an analytical method in a dimensionless form to solve the problem of transient heat conduction during the quenching process. Although dimensionless analysis once dominated before the rise of engineering software, its importance has been largely supplanted today by numerical approaches. Nevertheless, in multidimensional problems, dimensionless analysis remains effective through variable separation, under specific conditions that permit such separation. The study addresses a second-order transient parabolic partial differential equation with second- and third-kind boundary conditions, in a two-dimensional axisymmetric model of a cylindrical sample quenched in thermal oil. The solution is constructed by superimposing classical Grober-Heisler solutions for one-dimensional transient heat conduction in a cylinder and a flat plate. Based on this, a dimensionless analytical temperature field is formulated. In the author's earlier works, the same problem was solved numerically, enabling a direct comparison between analytical and experimental results. This study presents a temperature comparison between the dimensionless analytical solution and experimental measurements at the cylinder's centroid, followed by relevant conclusions.

Key words: dimensionless analysis, differential equation, axisymmetric, quenching, sample

1. Introduction

The dimensionless analytical method has long been fundamental in the study of heat transfer during sample quenching, although in recent years it has increasingly been replaced by numerical methods. In earlier studies [1]–[7], numerical results were compared with experimental measurements, highlighting the advantages and limitations of both approaches.

Dimensionless analysis, through the use of dimensionless numbers, reduces the number of unknowns and eliminates dependencies between variables in multidimensional problems. Although originally developed for continuous media, this work demonstrates that it can also be applied to discontinuous media with nonuniform boundary conditions

This study focuses on comparing the analytical dimensionless model with experimental measurements for a cylindrical sample with dimensions Ø25x100 mm quenched in the thermal oil Marquench 722. Details of the experimental setup, including the thermophysical properties of the fluid and quenching conditions, are provided in references [1]–[7]. The mathematical and thermodynamic formulation of the problem is also presented in these works. The temperature comparison was conducted at the canter of the cylinder.

2. Dimensionless formulation of the problem

In the general case, the temperature field for 2D axisymmetric unsteady heat conduction has the form

$$T = T(r, z, t), \tag{1}$$

and the differential equation describing his type of problem is the Fourier partial differential equation.

$$\frac{\partial T(r,z,t)}{\partial t} = a(T) \cdot \left(\frac{\partial^2 T(r,z,t)}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial T(r,z,t)}{\partial r} + \frac{\partial^2 T(r,z,t)}{\partial z^2} \right), \tag{2}$$

where $a(T)$ u m^2/s is the thermal diffusivity, which introduces nonlinearity into the problem. According to Grober-Heisler, under averaged boundary conditions, the solution can be expressed as a product of separated variables, i.e.,

$$T(r,z,t) = T(r,t) \cdot T(z,t). \tag{3}$$

Here, $T(r,t)$ represents the model of transient heat conduction through an infinite cylinder, while $T(z,t)$ represents the model of transient heat conduction through an infinite slab along the z-axis, as shown in Figure 1. Graphically, the intersection of these two models forms a 2D model of transient heat conduction through a cylinder of dimensions (*R,H*).

Each of the mentioned analytical models is described by its own differential equation.

2.1 Dimensional heat conduction equation in the r-direction

The differential equation governing transient one-dimensional heat conduction in the radial (r) direction is of the form

$$\frac{\partial T(r,t)}{\partial t} = a(T) \cdot \left(\frac{\partial^2 T(r,t)}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial T(r,t)}{\partial r} \right), \tag{4}$$

subject to two boundary conditions and one initial condition.
An adiabatic or second-kind boundary condition is applied at the cylinder axis for $r = 0$,

$$\left(\frac{\partial T(r,t)}{\partial r} \right)_{r=0} = 0. \tag{5}$$

while a third-kind (convective) boundary condition is applied at the cylinder surface $r = R$

$$-\lambda \cdot \left(\frac{\partial T(r,t)}{\partial r} \right)_{r=R} = \alpha(t) \cdot (T(R,t) - T_\infty). \tag{6}$$

The initial condition is

$$T(r, t=0) = T_0 = 850\ ℃. \tag{7}$$

The temperature field is a function of nine physical quantities of the form

$$T = T(r, R, t, \lambda, \alpha_1, \alpha_2, \alpha_3, a, T_0). \tag{8}$$

2.2 Dimensional heat conduction equation in the z-direction

The differential equation describing transient one-dimensional heat conduction in the direction of the z-axis is

$$\frac{\partial T(z,t)}{\partial t} = a(T) \cdot \frac{\partial^2 T(z,t)}{\partial z^2}. \tag{9}$$

subject to two boundary conditions and one initial condition.

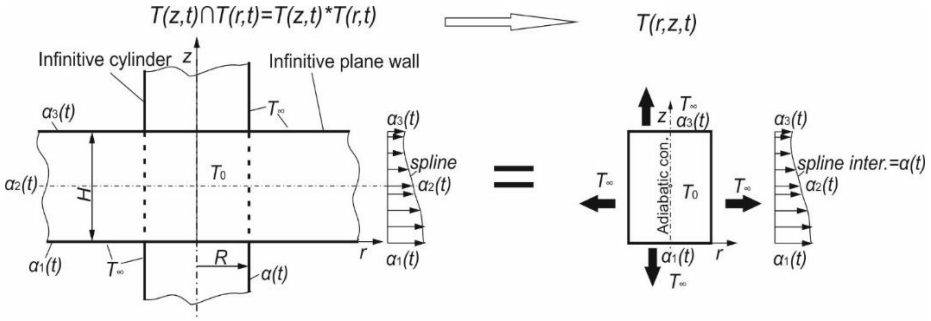

Figure 1. Intersection of two infinite models, represented as a product of separated variables

At the lower surface (the bottom base of the cylinder), a third-kind (convective) boundary condition is applied,

$$-\lambda \cdot \left(\frac{\partial T(0,t)}{\partial z}\right)_{z=0} = \alpha_1(t) \cdot (T(0,t) - T_\infty). \tag{9}$$

At the upper surface of the slab (the top base of the cylinder belongs to this surface), a third-kind (convective) boundary condition is also applied.

$$-\lambda \cdot \left(\frac{\partial T(H,t)}{\partial z}\right)_{z=H} = \alpha_3(t) \cdot (T(H,t) - T_\infty). \tag{10}$$

The initial condition is the same, namely $T(z,0) = 850$ °C .
The heat transfer coefficients $(\alpha_1, \alpha_2, \alpha)$ were taken from previously mentioned studies. The temperature field is a function of eight physical quantities of the form

$$T = T(z, H, t, \lambda, \alpha_1, \alpha_3, a, T_0). \tag{11}$$

2.3 Nondimensional form of the heat conduction equation in the radial direction

The dimensionless form of the differential equation for an infinite cylinder in the radial (r) direction, taken from [8], is

$$\tilde{c}(\Theta) \cdot \frac{\partial \Theta}{\partial F_o} = \frac{\partial}{\tilde{r}}\left[\breve{\lambda}(\Theta) \cdot \frac{\partial \Theta}{\partial \tilde{r}}\right], \tag{12}$$

where $\breve{\lambda}(\Theta), \tilde{c}(\Theta)$ are the dimensionless thermal conductivity and heat capacity of the cylinder, respectively. Their values were taken from [8], $\tilde{r} = r/R$ is the dimensionless radius. The dimensionless temperature is defined as

$$\Theta(\tilde{r}, F_o) = \frac{T(r,t) - T_\infty}{T_0 - T_\infty}, \tag{13}$$

ow the dimensionless temperature field is a function of two dimensionless numbers. At the cylinder axis, the dimensionless adiabatic (Neumann) boundary condition is of the form

$$\left(\frac{\partial \Theta}{\partial \tilde{r}}\right)_{\tilde{r}=0} = 0. \tag{14}$$

At the cylinder surface, there is a Robin boundary condition in dimensionless form.

$$-\breve{\lambda}(\Theta) \cdot \left(\frac{\partial \Theta}{\partial \tilde{r}}\right)_{\tilde{r}=1} = B_i(F_o) \cdot \Theta(1, F_o), \tag{15}$$

where the Biot number on the cylinder surface is equal to

$$B_i(F_o) = \frac{\alpha(F_o) \cdot R}{\lambda(T)}. \tag{16}$$

2.4 Nondimensional form of the heat conduction equation in the axial direction

The dimensionless form of the differential equation for a flat plate, taken from [8], is

$$\frac{\partial^2 \Theta}{\partial Z^2} = \tilde{a}(\Theta)\frac{\partial \Theta}{\partial F_o}, \tag{17}$$

where $Z = z/H$ is the dimensionless coordinate, and the dimensionless thermal diffusivity is defined as

$$\tilde{a}(\Theta) = \frac{t}{H^2} \cdot a\big(T(\Theta)\big). \tag{18}$$

With a third-kind (convective) boundary condition in dimensionless form on the lower surface of the plate

$$\frac{\partial \Theta(0, F_o)}{\partial Z} = -B_{i1} \cdot \Theta(0, F_o), \tag{19}$$

$$B_{i1}(F_o) = \frac{\alpha_1(F_o) \cdot H}{\lambda(T)}. \tag{20}$$

At the upper surface of the plate, a third-kind boundary condition is also imposed in its nondimensional form

$$\frac{\partial \Theta(1, F_o)}{\partial Z} = -B_{i3}(F_0) \cdot \Theta(1, F_o), \tag{21}$$

$$B_{i3}(F_o) = \frac{\alpha_3(t) \cdot H}{\lambda(T)}. \tag{22}$$

The dimensionless temperature is defined as

$$\Theta(Z, F_o) = \frac{T(z,t) - T_\infty}{T_0 - T_\infty}. \tag{23}$$

Now the dimensionless temperature field is a function of two dimensionless numbers.

2.5 The solutions of individual dimensionless equations

- For an infinite cylinder of radius *r*, taken from [8], is of the form

$$\Theta(\tilde{r}, F_o) = \sum_{n=1}^{\infty} A_n(t) \cdot e^{-\beta_n^2 \cdot Fo} \cdot J_0\big(\beta_n \cdot \tilde{r}\big), \tag{24}$$

where $A_n(t)$ are coefficients of the form

$$A_n(t) = \frac{2 \cdot B_i}{\beta_n^2 \cdot \big[J_0^2(\beta_n) + B_i^2(t) \cdot J_1^2(\beta_n)\big]}, \tag{25}$$

and β_n satisfies the implicit characteristic equation of the form

$$\beta_n \cdot J_1\big(\beta_n\big) + B_i \cdot (t) \cdot B_i \cdot J_0\big(\beta_n\big) = 0, \tag{26}$$

That is, β_n is the root of the zero-order Bessel function defined by $J_0(\beta_n) = 0$, and the quantities $J_1(\beta_n)$ are the values of the first-order Bessel function at the roots of the Bessel function.
The corresponding dimensionless numbers are

$$B_i(t) = \frac{\alpha(t) \cdot R}{\lambda(T)}, \qquad F_0 = \tau = \frac{a(t) \cdot t}{R^2}. \tag{27}$$

- The dimensionless temperature field for an infinite plate of thickness H with asymmetric Robin boundary conditions $\alpha_1(t)$ i $\alpha_2(t)$, taken from [8], is given by

$$\Theta(Z, F_o) = \Theta_s(Z) + \sum_{n=1}^{\infty} C_n \cdot e^{-\lambda_n^2 \cdot F_o} \cdot \phi_n(Z), \tag{28}$$

where is:

$$\Theta_s(Z) = \frac{B_{i3} \cdot (1 - Z) + B_{11} \cdot Z}{B_{i1} + B_{i3}}, \tag{29}$$

$$\phi_n(Z) = \cos(\lambda_n \cdot Z) + \frac{B_{i1}}{\lambda_n} \cdot \sin(\lambda_n \cdot Z) \text{ i} \tag{30}$$

λ_n are the positive solutions of the transcendental equation of the form

$$\lambda_n \cdot \sin(\lambda_n) + B_{i1} \cdot \cos(\lambda_n) + B_{i3} \cdot \cos(\lambda_n) + \frac{B_{i1} \cdot B_{i3}}{\lambda_n} \sin(\lambda_n) = 0. \tag{31}$$

- The superposition of the results in dimensionless form is the product of the dimensionless solutions of the form

$$\Theta(\tilde{r}, Z, F_o) = \Theta(\tilde{r}, F_o) \cdot \Theta(Z, F_o), \tag{32}$$

or in dimensional form

$$\left(\frac{T(r,z,t) - T_\infty}{T_0 - T_\infty}\right)_{cylinder} = \left(\frac{T(r,t) - T_\infty}{T_0 - T_\infty}\right)_{\substack{infinite \\ cylinder}} \cdot \left(\frac{T(z,t) - T_\infty}{T_0 - T_\infty}\right)_{\substack{infinite \\ plane\ wall}}, \tag{33}$$

From where the dimensional temperature field for the axisymmetric finite-dimension model is of the form

$$T(r,z,t) = T_\infty + (T_0 - T_\infty) \cdot \left[\left(\frac{T(r,t) - T_\infty}{T_0 - T_\infty}\right)_{\substack{infinite \\ cylinder}} \cdot \left(\frac{T(z,t) - T_\infty}{T_0 - T_\infty}\right)_{\substack{infinite \\ plane\ wall}}\right]. \tag{34}$$

Based on the previous analysis, a custom C++ code was developed, whose pseudocode is as follows:

- Define physical parameters of the cylinder (R=0.0125, H=0.1, T_0=850 ^{0}C, $T\infty$ = 90 °C, ρ=7950, etc.)
- Define time simulation parameters (t_max, dt, N)
- Load data from files:
  - h1(t), h2(t), h3(t)
  - Tm(t) - measured temperatures
- For each time step t = i*dt (i = 0..N):
  a. Interpolate h1, h2, h3 at current time t
  b. Compute effective heat transfer coefficient h_side on the cylinder shell
  c. Optionally write h coefficients to CSV
- Compute constants for normalization (sumAn0, sumBm0)

- Initialize T_sim[0] = T0+
- For each time step i = 1..N:

a. Set T_prev = T_sim[i−1]
b. Iterate to compute T_iter:
- Compute α(T_iter)
- Compute θ_z(t) (z-component of solution)
- Compute θ_r(t) (r-component of solution)
- Get analytical solution T_analyt
- Compute convective cooling T_conv
- Blend: T_new = (1−w)·T_analyt + w·T_conv
- Check for convergence; if reached, exit loop

c. Set T_sim[i] = final T_iter
d. Interpolate Tm(t)
e. Print t, T_sim, Tm to screen

- At the end: write all results (t, h1, h2, h3, h_side, T_sim, Tm) to a CSV file

3. Discussion and comparison of obtained results

Previous studies, from [1] to [7], presented successful comparisons between measured and numerically simulated results. In this study, we compare analytical solutions based on the Grober-Heisler approach as described in [8]. The upper graph in Figure 2 shows the heat transfer coefficients that generate the observed temperature field, which were taken from earlier works. The lower graph in Figure 2 presents a comparison between measured and analytically calculated temperatures at the center of the cylinder.

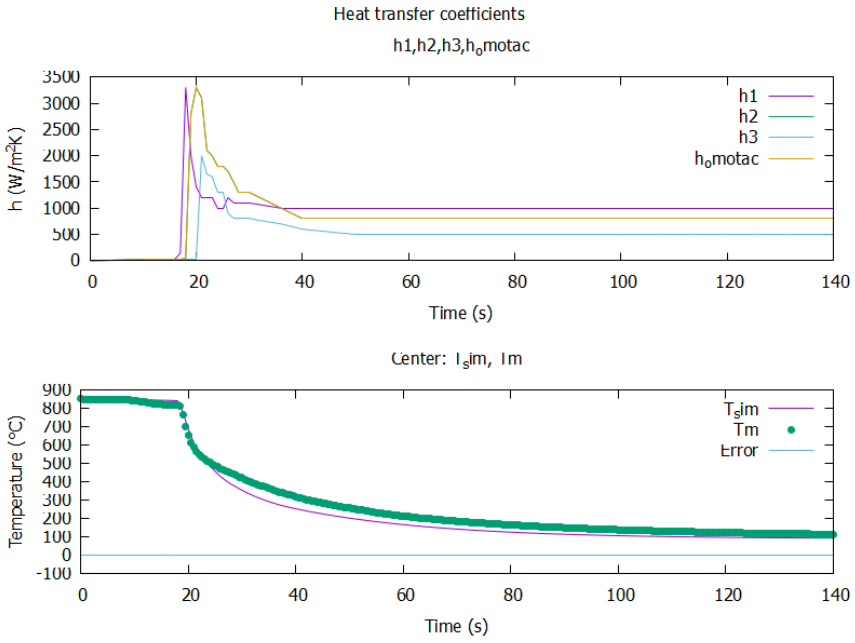

Figure 2. Comparison of analytical and experimental temperatures at the center of the cylinder Ø25×100 mm during quenching in thermal oil 90 °C

From 0 to 26 seconds, the comparison results show deviations below the strictly acceptable threshold of 3%. Between 30 and 45 seconds, the deviations reach a maximum of approximately 6%. This period of increased simulation error is attributed to the temperature-dependent physical properties of the probe material, as well as to boundary conditions derived from earlier studies that have coarse time resolution. From 45 to 140 seconds, the deviations again remain below 3%. Previous analyses attempted a graphical-

analytical solution using direct readings from Grober-Heisler dimensionless temperature charts, applied separately to an infinite cylinder and an infinite plate. These solutions were then multiplied to obtain a combined result. The outcome of this approach, compared to numerical and experimental data at the cylinder center, is presented in Figure 3.

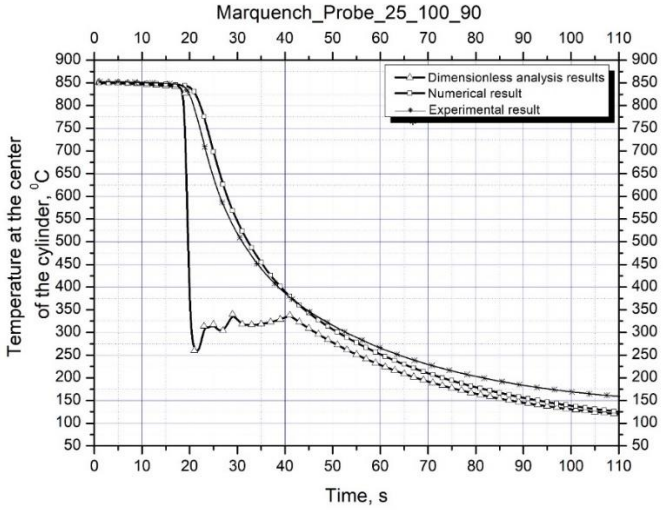

Figure 3 Comparison of the dimensionless graph-analytic solution, measured, and numerical temperature solutions at the center of the cylinder

In the heterogeneous region of nucleate boiling, the convection coefficient values defined at sparsely sampled time intervals led to uncontrolled and inconsistent results. In contrast, within the homogeneous region, the comparison was satisfactory and within acceptable limits.

4. Conclusion

In this study, a classical analytical (dimensionless) model was validated through comparison with experimental temperature measurements. Unlike previously published works that focused on numerical methods, this research evaluated the accuracy of the analytical approach. The maximum deviations were recorded between 30 and 45 seconds and amounted to approximately 6%, while in the remainder of the process, the error remained below 3%.

The results confirm that analytical methods, despite their simplicity, can provide useful estimates, though their applicability is limited under more complex conditions. Numerical methods remain superior for analyzing nonlinear and real-world problems due to their flexibility and precision. Nevertheless, dimensionless methods retain an important role in understanding physical phenomena and in the initial stages of modeling. In short: *analytical methods explain, numerical methods compute* — both remain complementary in modern engineering practice.

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Terminological Challenges and Standardization in Mechanical Engineering

Hatidže Burnić

Faculty of Technical Engineering, University of Bihać, Bihać, B&H

E-mail: hatidze_b@hotmail.com

Abstract: Technical terminology in mechanical engineering plays a crucial role in ensuring precise and functional communication among professionals from different linguistic and technical backgrounds. This paper analyzes key categories of technical terms in mechanical engineering – from fundamental concepts to specialized expressions in automation and mechatronics – with a particular focus on the German terminological system and the challenges of its application and translation into Bosnian.

Using a descriptive-analytical and contrastive method, the study explores polysemy, the structure of German compound terms, technical phrases, and the use of untranslated or partially translated expressions. The analysis is based on examples drawn from technical documentation and DIN-standardized terms.

The aim of this paper is to highlight the importance of terminological competence as an interdisciplinary skill that encompasses linguistic knowledge, technical expertise, and contextual sensitivity. The findings point to the need for a systematic approach to teaching technical language in mechanical engineering, with particular emphasis on multilingual professional communication and translation accuracy.

Keywords: Technical terminology, mechanical engineering language, standardization, translation challenges

1. Introduction

Specialised terminology forms the foundation of effective and precise communication across all technical disciplines, and this is particularly evident in the field of mechanical engineering, where the complexity of concepts requires clearly defined and standardised expressions. The language of the mechanical engineering profession is shaped by specific terms that describe machine components, production processes, materials, automation principles, and other aspects of engineering practice. A proper understanding and use of technical terms is essential not only for the successful execution of engineering tasks, but also for mutual comprehension within international teams.

In the contemporary context of globalisation and increasing mobility of professionals, there is a growing need for comparable and translatable terminological systems. German, English, and Bosnian are used in various forms of technical education, research, and professional practice. However, differences in linguistic structures – especially regarding compound words (*Komposita*) in the German language – can pose significant challenges to accurate meaning transfer.

This paper explores the key aspects of terminology in the field of mechanical engineering, with a particular focus on multilingual comprehension, standardisation, and translational challenges. Through an analysis of core concepts, normative frameworks, and concrete examples from practice, the study aims to highlight the importance of terminological precision in education and professional communication.

2. Technical Terminology – Definition and Function

According to DIN 2342 (2022), terminology is defined as "the complete set of concepts and their designations within a specialised field" (*Gesamtbestand der Begriffe und ihrer Bezeichnungen in einem Fachgebiet*). Accordingly, technical terminology refers to the body of specialised terms used within a specific domain to enable precise and unambiguous communication among professionals. In the context of mechanical engineering, it includes the names of machine elements, technical processes, materials, measurement units, testing methods, and other relevant concepts essential for describing constructions, production procedures, and engineering solutions.

Unlike general language, technical terminology is characterised by univocity, systematisation, and a functional orientation. A term does not merely serve as a label; it conveys specific meaning rooted in the knowledge and practice of a particular discipline. In this way, specialised expressions function as tools for information exchange, technical decision-making, and the documentation of work in accordance with professional standards.

In modern technical communication, terminological precision also carries legal, safety-related, and economic implications. The use of inaccurate or inappropriate terms may result in misunderstandings within project teams, technical errors during production, and even serious consequences concerning product safety. For this reason, organisations such as DIN (Deutsches Institut für Normung) have developed systematic terminological standards for various areas of technical practice.

As Felber (1984) points out, terminology represents “a system of expressions that reflects a system of knowledge,” rather than a mere list of words. It is closely linked to the evolution of scientific and technical disciplines, as it mirrors their structure and dynamics. In this sense, the development of terminology in mechanical engineering cannot be separated from the advancement of engineering knowledge and professional practice itself.

3. Key Categories of Terminology in Mechanical Engineering

Technical terminology in mechanical engineering can be systematised according to functional domains that reflect the core components of the discipline. This classification not only facilitates learning and comprehension but also supports the structuring of technical dictionaries and educational materials.

3.1 Fundamental Technical Concepts

This category includes terms that denote essential mechanical and physical principles—such as force, torque, friction, stress, or deformation. Mastery of these concepts forms the foundation for all further professional understanding in the field.

As noted by Arntz, Picht, and Mayer (2014), specialised terminology often involves cases of *partial overlapping*, that is, partial equivalence of concepts across different languages. This underscores the importance of precisely defining and interpreting each term within the framework of its respective discipline.

3.2 Machine Elements

This category includes standardised machine components such as gears, bearings, shafts, screws, nuts, pins, and similar elements. Each of these components has a precisely defined name, often related to its function, shape, or manufacturing process. Standardisation in this area frequently relies on norms such as DIN 720 (for bearings) and DIN 5480 (for spline shafts).

3.3 Materials

Material-related terminology comprises names and designations for various types of metals, alloys, plastics, and composites, as well as their mechanical properties (e.g. *Zugfestigkeit*, *Härte*, *Korrosionsbeständigkeit*). In the German language, these terms often include combinations of numbers and codes based on standards such as DIN EN 10027-1 for steel. Translating these terms requires particular caution, as incorrect identification of materials may lead to serious technical issues (DIN, 2016)

3.4 Production Processes

Within the specialised language of mechanical engineering, the terminology of production processes encompasses a range of terms related to various material processing technologies. Among the most commonly encountered are turning (Drehen), milling (Fräsen), welding (Schweißen), and heat treatment (Wärmebehandlung).

Each of these processes has its own terminological system, which includes the names of methods, tools, operational parameters, and procedures for quality control. Terminological clarity in this domain is essential for the correct planning, execution, and documentation of manufacturing operations.

3.5 Automation and Mechatronics

In modern mechanical engineering, the terminology of automation encompasses terms originating from electrical engineering, electronics, and programming—such as *SPS* (Programmable Logic Controller), *Sensorik*, *Aktoren*, *Lager*, *Linie*, and others. Due to the interdisciplinary nature of this field, these terms are frequently used in their original German or English form where necessary (Picht & Draskau, 1985). As the authors point out, "the borrowing of terms in specialised language is a common practice when the goal is to preserve terminological precision and ensure international consistency."

Nevertheless, such borrowed terms often undergo adaptation into the target language, in this case Bosnian. A typical example is the term *Sensorik*, which refers to a system of sensors and their functions in automation systems. Instead of translating it as “sensor technology” or “sensory systems,” the term is often retained in its original form to avoid semantic imprecision and to maintain consistency with international technical documentation.

In the Bosnian language, adaptation is carried out on the phonological, graphemic, and morphological levels, with minimal modifications that preserve the recognisability of the original term. For instance, *Sensorik* is adapted as *senzorika* by adding a domestic suffix and changing the grapheme “s” to “z,” thus facilitating integration into the Bosnian linguistic system.

4. Challenges in Translating and Applying Technical Terms

This section examines the specific challenges related to the translation and use of technical terms in multilingual contexts, with particular attention to compound terms, polysemy, and conceptual differences that can affect terminological precision and communication.

A deeper analysis reveals that translating technical terms in the field of mechanical engineering requires much more than basic language proficiency—it demands a thorough understanding of the technical context, the structure of the source language, and the functional role of terms in actual engineering applications.

This complexity is especially apparent in the German language, whose technical terminology is characterised by long compounds with clearly defined semantic structures and a high degree of precision. This underscores the need for domain-specific language proficiency (Rösler, 2023).

One of the central challenges in translating technical terminology lies in the fact that linguistic differences go beyond grammar and syntax—they reflect distinct concepts, categorisations, and technical ways of thinking. German technical language is shaped by a normative and productive terminological system in which technical meanings are conveyed through compounds that often carry specific cultural and technological references. In contrast, Bosnian technical discourse frequently relies on broader, more descriptive, or less precise expressions, which can hinder the direct transfer of meaning without loss of terminological clarity.

In such a context, successful translation of technical terms involves more than formal linguistic equivalence—it requires the ability to analyse terminological units, identify their meaning within the given technical environment, and interpret them in accordance with engineering practice and international standards. As emphasised by Picht and Draskau (1985), a term cannot be viewed merely as a linguistic sign; it must be analysed through a three-dimensional model that includes linguistic, conceptual, and

communicative aspects. This approach enables a deeper understanding of a term's meaning, its position within a professional domain, and the way it functions in specialised communication.

Particular attention must be paid to structural differences between languages—especially in cases where a German compound needs to be translated into a descriptive phrase in Bosnian. Such cases require additional effort to achieve terminological consistency and functional clarity.

Terminological competence in technical communication requires continuous development, particularly in recognising polysemous expressions, understanding specialised technical phrases, and managing terms that—due to international standardisation—are often retained in their original form. A lack of precision in this domain may result not only in linguistic misunderstandings but also in serious technical, safety-related, and legal consequences during the implementation of engineering projects. These challenges are especially pronounced in multilingual projects, the drafting of technical documentation, and collaboration on international engineering platforms, where terminological accuracy plays a crucial role in ensuring effective communication.

Therefore, terminological competence is increasingly recognised as an interdisciplinary skill that requires a combination of linguistic knowledge, technical expertise, and intercultural communication ability. In this context, terminological dictionaries, databases, and digital terminology management tools have become indispensable resources for ensuring consistency and quality in technical documentation.

Terminological competence in mechanical engineering comprises a range of complex aspects that are essential for the accurate and functional translation of specialised terms.
The following subsections will address key challenges in terminological practice, including the polysemy of terms and their contextual interpretation, the structural characteristics of German compounds, the role of phrases as more complex terminological units, and the issue of untranslated and partially translated terms. This analysis aims to highlight the various dimensions of terminological precision and to provide a better understanding of the processes of translational adaptation in multilingual professional environments

4.1 Contextual Ambiguity and Polysemy of Terms

One of the common challenges in the use and translation of technical terms is the polysemy of words that are also used in general language. In technical contexts, such words often acquire highly specific meanings. If the translator or user fails to recognise the technical context, serious misinterpretations may occur.

For example, the noun *Druck* in everyday German refers to "pressure" in the psychological or social sense. However, in technical terminology—as defined in the Langenscheidt dictionary (Schmitt, 2012)—this term denotes a physical force exerted over a unit of surface area. In the term *Druckluft*, it refers to compressed air used in pneumatic systems, whereas in *Druckspannung*, it denotes stress caused by compressive force acting on a material. Failing to recognise the technical meaning of such terms can lead to incorrect interpretations of engineering data and improper application of design solutions.

A similar terminological ambiguity arises with the verb *ziehen*. In general usage, as defined in the Duden dictionary (Dudenredaktion, 2023), *ziehen* means "to pull" or "to drag," but in technical contexts it refers to specific material processing operations. In the term *Drahtziehen*, it describes an industrial procedure of drawing wire through a series of dies to reduce its diameter. A literal interpretation of this term may result in a misunderstanding of the actual process.

Another illustrative example is the word *Gang*, which in everyday German denotes a hallway or passage. However, in mechanical and automotive terminology, *Gang* refers to a gear stage in a transmission system. The expression *erster Gang*, therefore, means first gear, not a spatial element. Failure to recognise this distinction may lead to serious errors when translating technical manuals or documentation.

These examples clearly highlight the importance of contextual understanding in the interpretation of technical terms. Polysemy and semantic divergence between general and specialised language require a high level of terminological sensitivity, particularly in multilingual professional settings and during technical translation, where precision is critical. As Felber (1984) emphasises, a term must be interpreted within a clearly defined professional context in order to avoid terminological errors and ensure communicative efficiency in technical disciplines. A similar position is expressed by Arntz, Picht, and Mayer

(2014), who note that "without semantic and functional contextualisation, a term cannot fulfil its communicative purpose, particularly in specialised languages."

4.2 Structure and Challenges of Compound Terms

The German language is rich in compound words that merge multiple concepts into a single term, with the core concept typically placed at the end. This characteristic is particularly evident in the specialised terminology of mechanical engineering, where precision is often achieved through the construction of long compounds with clearly defined semantic hierarchies. In this context, complex terminological units frequently contain meanings that cannot be clearly understood by analysing their individual components in isolation. Therefore, a detailed linguistic analysis is required to accurately interpret their function and meaning within a technical context (cf. Wustmann & Schmitz, 2006).

In compound terms, the descriptive element usually appears at the beginning, while the key term that carries the main meaning stands at the end. Since Bosnian tends to translate such terms descriptively, there is a risk of losing precision or altering meaning if the internal structure of the expression is not properly analysed. An additional challenge lies in the syntactic order: whereas German compounds structurally end with the core term, Bosnian translations often begin with it.

For example, the term *Zugfestigkeit* (tensile strength) consists of *Zug* (tension, pulling) and *Festigkeit* (strength), and refers to a material's resistance to tensile stress prior to breaking. Without an understanding of the technical context, this term might be mistakenly interpreted as general strength, overlooking its specific mechanical dimension. A similar situation arises with the term *Kraftübertragungssystem* (force transmission system), which includes three components: *Kraft* (force), *Übertragung* (transmission), and *System* (system). In Bosnian, this term requires a more detailed, multi-word translation that clarifies the relationships among the components.

One of the more complex terms is *Druckgussverfahren*, composed of *Druck* (pressure), *Guss* (casting), and *Verfahren* (process). Although the literal translation "pressure casting process" may appear understandable, it in fact refers to a specific metal forming technology involving the injection of molten material into a mould under high pressure. Inadequate comprehension may lead to a misinterpretation of the technological process.

Another illustrative example is the term *Schweißnahtfestigkeit*—a compound combining *Schweiß* (welding), *Naht* (seam), and *Festigkeit* (strength). This term denotes the strength of a welded joint and requires knowledge of both the welding process and the mechanical characteristics of joints. Without such knowledge, the compound might be mistakenly interpreted as a simple reference to a "strong weld."

Therefore, understanding compound terms in mechanical engineering terminology goes far beyond basic vocabulary knowledge. It requires mastery of the specific rules of word formation in German, as well as in-depth technical expertise to accurately interpret meaning in context. The terminological precision and compactness typical of German often contrast with the descriptive nature of Bosnian expressions, where equivalents require multiple words and additional clarification. This structural disparity represents one of the key challenges in translating and applying specialised terminology in international contexts. As Wüster (1979) states, "A compound term must be understood as a unified semantic entity, not as a mechanical sum of its parts."

4.3 Phrases in Technical Language

Another significant challenge in the specialised terminology of mechanical engineering is the correct interpretation and translation of phrases—stable combinations of words that together convey a specific meaning. Unlike compounds, phrases are not single fused words but rather multi-word combinations that form a terminological unit. Their meaning often cannot be deduced from a literal translation of the individual components.

In technical contexts, the meaning of phrases depends heavily on the industrial and technological setting in which they are used. Their interpretation may vary depending on the application, and literal translations are often inadequate. Moreover, the same phrases may have entirely different meanings in everyday language, which further complicates their use in specialised terminology.

While understanding the internal structure and relationships of word elements is essential for interpreting compounds, recognising the broader technical context is crucial when dealing with phrases. One cannot rely solely on the literal meanings of individual words—it is necessary to understand their function within a technical system or process.

Phrases such as *unter Spannung stehen*, *Aufmaß nehmen*, or *Fressen einer Welle* cannot be translated literally without losing their technical meaning. These idiomatic units function as terminological wholes and often require paraphrasing or contextual explanation to be accurately interpreted.

For example, the phrase *unter Spannung stehen* literally translates to "to be under tension." However, in mechanical terminology, it refers to a condition in which structural components or materials are subjected to internal or external forces that cause stress. It is frequently used in the context of static calculations and strength analysis.

Similarly, the phrase *Fressen einer Welle* does not mean "to devour a shaft" in a literal sense; rather, it describes a failure mode where insufficient lubrication or excessive loads cause damage or seizure of the shaft within the bearing.

Another example is *Aufmaß nehmen*, which literally means "to take measurements." In technical practice, however, the phrase refers to the precise measurement of components before their production or installation, with the aim of ensuring dimensional accuracy (DWDS, n.d.).

These examples clearly demonstrate how literal translation can lead to misunderstanding and how context is key to correct interpretation. In Bosnian, there is often no direct equivalent, so paraphrasing or descriptive expressions are necessary to retain technical accuracy.

Therefore, translating phrases in mechanical terminology requires not only linguistic competence but also the ability to analyse their meaning within technical processes. This skill is essential to ensure accurate and functional communication in international professional environments.

4.4 Untranslated and Partially Translated Terms

In the specialised language of mechanical engineering, terms that lack adequate equivalents in the Bosnian language are frequently used. These expressions, borrowed from German and English, are often retained in their original form to preserve precision and facilitate international communication. They have become an integral part of technical literature, industrial practice, and academic research, as they allow for accurate and efficient exchange of technical information.

Due to international standardisation and the need for technical accuracy, many terms in mechanical engineering remain untranslated. This includes expressions such as *Moment*, *Prozess*, *CNC-Maschine*, *Hydraulik*, *Guss*, among others. Hybrid forms also appear frequently—such as *CNC-mašina*, *švajs-aparat*, or *pneumatski cilindar*—where the international root is preserved, while a part of the expression is adapted to the local language.

However, some expressions cannot be translated literally, as such translations may lead to terminological imprecision. These expressions often belong to standardised technical terminology and are recognised as universal in the industry. They are so firmly established in the mechanical engineering lexicon that they are used without translation, even when Bosnian equivalents exist.

Examples include:

- *Moment* – retained in technical specifications due to its precision and widespread application in power and load calculations.
- *Guss* – although the Bosnian term *livenje* exists, the German term *Guss* is often used, especially in technical drawings and documentation, where it denotes a specific metal forming process.
- *Prozess* – a standard term in production and technological systems that refers to workflows and technological procedures.

In addition to completely untranslated expressions, there are also terms that have one meaning in everyday language but acquire a specific technical meaning in mechanical engineering. For instance:

- *Kanal* – while in general usage it refers to a channel or watercourse, in a technical context it can denote a guideway in machine tools or a passage for cables and fluids.

It is also common in the mechanical industry to encounter partially translated compounds, where one part of the term is retained in the original language while the rest is adapted into Bosnian. These hybrid expressions enhance comprehensibility while maintaining technical precision. Examples include:

- *CNC-mašina* (*CNC-Maschine*) – the acronym is retained in English, while the word *mašina* is adapted to Bosnian.
- *Švajs-aparat* (*Schweißgerät*) or *zupčasta pumpa* (*Zahnradpumpe*) – only the first part of the compound is borrowed and combined with a domestic term.

These examples confirm that untranslated terms are not used merely for convenience, but also to meet the demands of terminological precision and global standardisation in industry. In many cases, literal translation could result in a loss of meaning or cause terminological confusion, which is why professionals in practice often prefer to use foreign expressions.

The use of untranslated and partially translated terms in mechanical engineering enables more precise and efficient professional communication. While fully untranslated terms ensure international intelligibility, partially translated expressions help integrate foreign concepts into the local language, thereby striking a balance between technical accuracy and practical usability in professional environments.

Taken as a whole, the challenges associated with the translation and application of technical terms require careful consideration of their linguistic, conceptual, and functional dimensions. Polysemy, compounds, phrases, and untranslated terms constitute complex elements that must be understood and properly interpreted to ensure terminological clarity and effective communication. Therefore, continuous development of terminological competence and the use of appropriate tools are essential to overcoming these challenges—particularly in international and multilingual professional contexts.

5 Conclusion

The analysis of technical terminology in mechanical engineering has shown that effective and precise communication in engineering practice depends on the ability to interpret terms within their actual context. By identifying key terminological categories and examining phenomena such as polysemy, compound words, technical phrases, and untranslated terms, the study confirms that technical terminology functions not only as a linguistic system but also as a conceptual tool connecting language with specific technological processes and international standards.

This research contributes to the systematization and deeper understanding of the functional role of terminology in mechanical engineering, highlighting the importance of integrating linguistic and technical knowledge in both education and professional contexts. It opens avenues for further research in the fields of language for specific purposes, translation studies, and terminology training, particularly with regard to developing didactic models for teaching terminology in multilingual environments.

Standardization, international consistency, and digital terminological tools remain key challenges in contemporary technical education and professional collaboration. As such, terminological competence is increasingly recognized as an interdisciplinary and dynamic skill that requires continuous development and the use of appropriate resources to ensure accuracy, efficiency, and clarity in global professional communication.

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Design Energy Efficiency of the Existing Urban Potable Water Supply System

Begić Aladin

University of Bihać, Faculty of Technical Engineering, Bosnia and Herzegovina

E-mail: aladin.begic@web.de

Abstract. In the design of water supply networks in accordance with EN standards, it is essential to account for the projected population growth of the city in order to properly dimension pressure and flow rates at the potable water inlet to the municipal distribution system. Forecasts of demographic and infrastructural developments are typically made for a planning horizon of 15 to 30 years, and the water supply system must be capable of meeting future demand. This study evaluates the energy efficiency of the existing potable water supply system in the city of Bihać, which sources its water from the Privilica and Klokot springs. The system relies on gravity-based distribution to deliver water to urban areas. Gravity-fed systems are most common in small towns, whereas medium-sized cities typically employ a combination of gravity and pumping to optimize distribution. In large urban centers, water supply is predominantly pump-driven. In this particular case, it was observed that certain sections of the city—especially residential buildings located near the junction between the main and distribution pipelines—experience inlet pressures exceeding 7 bar, which is above the rated pressure of typical household plumbing fixtures. The analysis indicated that the municipal water utility failed to implement appropriate pressure regulation, resulting in additional expenses for residents who were compelled to install pressure-reducing valves. The primary cause of the excessive pressure is the higher elevation of the gravity-fed reservoirs relative to the distribution zones. The study provides a comprehensive analysis of the issues associated with elevated pressure, including an economic assessment of the burden placed on end users. Furthermore, it proposes technical measures aimed at optimizing the system. The recommendations focus on improving the energy efficiency of the existing potable water supply infrastructure in urban settings, with the goal of reducing operational and user-related costs while enhancing overall system performance.

1. Introduction

Modern design and optimization of water distribution networks require the integration of long-term demographic and infrastructural projections. Within the framework of European standards such as EN 805 and EN 752, the planning of potable water distribution systems must account for anticipated population growth and the expansion of urban zones. The design of water supply networks should be based on accurate forecasts of demographic trends over a planning horizon of 15 to 30 years.

The city of Bihać faces challenges typical for medium-sized urban areas that rely on a combination of gravity-fed and pump-assisted water supply systems. The efficiency of the water supply system directly affects the quality of life for residents and the economic costs borne by the local community. Population growth and urbanization result in increased demands for a reliable and energy-efficient water supply. System design must be flexible, adaptable to change, and resilient to unforeseen conditions.

It is essential to analyze the current state of the system in order to identify weaknesses and propose improvement measures. This study focuses on the energy efficiency of the existing water supply system sourced from the Privilica and Klokot springs. The analysis includes measurements of pressure and flow at the junction points where the main pipelines from both sources connect to the city's distribution network. All key components of the network are examined, and optimization measures are proposed to improve system performance.

2. Description of the Existing Water Supply System

The existing water supply system in the city of Bihać utilizes the Privilica and Klokot springs as sources of potable water for the urban area. Each spring is connected to its own reservoir, located at elevations above their respective sources, as shown in Figure 1. From each reservoir, water is conveyed by gravity through a

transmission pipeline into the city's distribution pipe network. The connection points between the gravity-fed mains and the urban distribution network are also illustrated in Figure 1.

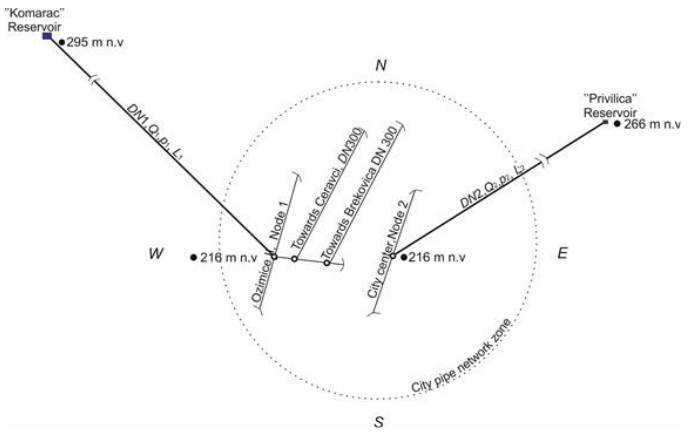

Figure 1. Schematic Diagram of the Connection Between Main Gravity Pipelines and the Urban Pipe Network

These springs supply the city and its immediate surroundings with water of stable quality; however, the volumetric and energy demands vary depending on the elevation, which is related to the static water pressure, and the consumption zones, which correspond to water flow rates. The gravity-fed system is efficient in the lower parts of the city but is insufficient for elevated zones that rely on pumping stations.

This combination of connecting the main gravity pipelines with the urban pipe network causes uneven pressures throughout the system, where some areas of the city experience excessively high pressures, while others suffer from low pressures due to reduced water flow. It is evident that the design parameters of the network, particularly the pipelines, are outdated and do not comply with current standards.

The system underutilizes the potential for energy recovery by not exploiting the difference between excessive pressures and the standard operating pressures within the pipeline network. Furthermore, the system inefficiently balances pressure loads within the network.

The locations for hydraulic parameter analysis correspond to the connection points between the main pipelines and the city's distribution network, which constitute the primary focus of this study.

3. Theoretical Foundations

The fundamental theoretical equations required for solving such problems are based on the first two conservation laws, namely the conservation of mass and the conservation of energy in steady-state flow. The conservation of mass for incompressible fluids reduces to the continuity equation for the i-th node in a pipe network, analogous to Kirchhoff's first law for electrical currents. The sum of all flows into and out of a node equals zero, considering any external sources or sinks at that node. Under steady-state conditions, this can be expressed as

$$\sum_{k \in I_i} \pm Q_{ik} \pm Q_{vi} = 0, \tag{1}$$

where

$\pm Q_{ik}$, m^3/s $-$ volumetric flow rate in pipe k, $\pm$pipe k enters (inlet) or leaves (outlet) node i,
$\pm Q_{vi} -$ source or sink (consumer) at node i,
I_i the set of pipes connected to node i.

The second conservation law is the conservation of energy, applied to each closed loop j. For a real fluid, the sum of all energy losses (pressure drops) within a closed loop is equal to zero, that is:

$$\sum_{k\in C_j} \pm\Delta p_k(Q_k) = 0, \tag{2}$$

where

$\pm\Delta p_k(Q_k)$, Pa is the pressure loss in pipe k, which is part of the loop set C_j and is calculated according to, [1]

$$\Delta p_k(Q_k) = \rho \cdot \left(\lambda_k \cdot \frac{8 \cdot l_k}{d_k^5 \cdot \pi^2} + \sum_{i\epsilon k} \xi_i \cdot \frac{8}{d_k^4 \cdot \pi^2} \right) \cdot |Q_k| . Q_k \tag{3}$$

In Equation 3, the quantities λ_k, l_k, d_k represent the friction factor, length, and diameter of the k-th pipe, respectively, while ξ_i denotes the local loss coefficient for the i-th fitting in the k-th pipe. The flow rate Q_k is entered numerically according to the sign convention.

An example of a hydraulic analysis of a pipe network, with labeled nodes, pipes, and the direction of traversal for each loop, is shown in Figure 2.

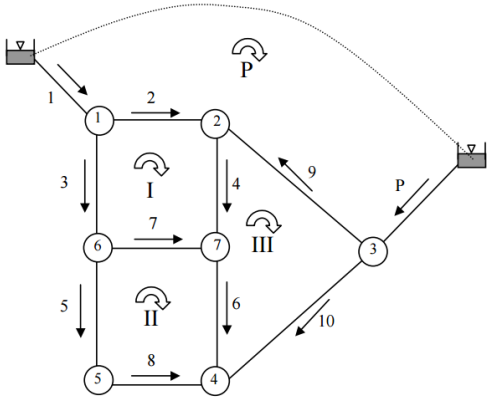

Figure 2. Example of Hydraulic Analysis of a Pipe Network with Defined Loops and Assumed Flow Directions

4. Analysis of the Connection Between Gravity and Pumped Pipelines

This study presents an energy and flow analysis of the nodes where both gravity pipelines connect to the local distribution network. The static pressure and flow at these nodes have a direct impact on the urban section of the pipeline network. The hydrodynamic analysis of the connection points between the gravity mains and the city's distribution network is reduced to the evaluation of static pressure and flow for each stream. Figure 3 shows the connection point of the Komarac gravity main at the Ozimice location.

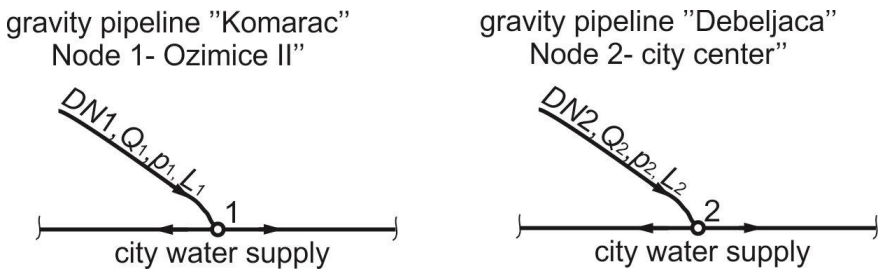

Figure 3. Nodes Connecting Gravity Pipelines to the Urban Pipe Network

Table 1 provides an overview of input and measured data for the gravity pipelines near the connection points.

Table 1. Overview of the Analysis of Nodes 1 and 2

Measuring point	Nominal diameter mm	Length, m	Static pressure, bar	Flow rate, l/sec	Remark
Node 1	400	3200	8	120	Pressure regulation required
Node 2	300	1500	5	70	Pressure regulation required

The elevations of the reservoirs are shown in Figure 1. The hydrostatic pressure of the water column, when water consumption is negligible (e.g., three hours after midnight), corresponds to the available total pressure from the gravity mains. At this time, the pipelines and residential buildings experience the highest pressure forces. The Komarac reservoir is located at an elevation of 80 meters above the network's reference level, while the Debeljača reservoir is at 50 meters elevation, corresponding approximately to pressures of 8 bar and 5 bar, respectively. According to BAS EN 806-4, the operating pressure in residential buildings should be between 3 and 4 bar.

5. Consequences of the Total Energy Analysis at the Pipeline Network Inlet

Excessively high water pressure at the inlet to the pipeline network is a direct cause of increased pressure within residential buildings. In housing units located near the junction of the main and distribution pipelines, measured pressures of approximately 8 bar have been recorded, which is twice the upper limit of the standard operating pressure for potable water of 4 bar. The test pressure for residential plumbing fittings, according to BAS EN 806-4, is 6 bar.

Consequently, frequent failures, leaks, and additional costs for end users occur. It is necessary to implement pressure mitigation measures, including the installation of pressure-reducing valves and network zoning. Additionally, educating the population about the risks and potential solutions is important to increase the resilience of the pipe system.

The economic impact on users due to high pressure in the water supply network directly affects household budgets. Residents are forced to invest in pressure-reducing valves, which represent an additional expense. Moreover, increased wear of installations leads to frequent breakdowns and leaks, requiring frequent plumber interventions. Furthermore, high pressure increases the risk of damage to household appliances connected to the water supply. For example, the solenoid valve in a washing machine will not open properly at pressures exceeding 4 bar.

6. Technical Measures for Optimizing Total Energy at the Pipeline Network Inlet

The first recommendation is the installation of automatic pressure regulators immediately before the connection of gravity pipelines to the distribution network, to protect plumbing installations in residential buildings. Modern water supply networks aiming for energy efficiency benefit not only technically but also reduce operational costs for system operators. Integration with SCADA (Supervisory Control and Data Acquisition) systems enables automation and remote control of pump valves and pumping stations.

The second recommendation concerns the introduction of mini hydropower turbines at locations just before the potable water enters the distribution section of the pipeline network, where static pressure is highest. This setup would convert excess pressure energy into electrical energy. Additionally, turbines act as natural regulators of static pressure, reducing the need for mechanical pressure-reducing valves. Installation of mini turbines requires minimal civil works, and the investment is recovered over time through energy savings. The turbine runners are mostly axial flow or Kaplan type, which offer minimal local resistance to the main potable water flow. Pilot projects in European cities have demonstrated a payback

period of less than five years for mini turbine installations. These turbines can be connected to the local electricity distribution system or used to power local pumps and metering stations.

The third measure is zoning the network according to elevation levels to better control pressures within local zones. Zoning facilitates management and allows individualized pressure regulation approaches in different parts of the pipeline network. It is important to introduce automatic pressure-reducing valves in unregulated zones to avoid the need for individual installations at consumers' premises.

Nowadays, it is necessary to install intelligent metering stations that monitor pressure and flow in real time and transmit data to the control center. Together, these elements constitute a modernization that can significantly improve the existing system.

Standardization of water supply systems is reflected in European standards (EN) that define minimum technical requirements for safety, quality, and efficiency. For example, EN 805 prescribes the design, construction, and management of water supply systems outside buildings. It is recommended to apply EN 1508 for the delivery of potable water, which includes hydraulic and quality requirements. Pressure management must comply with guidelines for consumer protection, particularly regarding test and operating pressures of fittings. Furthermore, EN 14339 relates to the design and installation of potable water reservoirs, including gravity systems.

Local regulations in Bosnia and Herzegovina require the preparation of technical documentation and energy balances for all public water supply systems. The existing system in Bihać partially meets these requirements but lacks pressure and flow regulation in critical zones of the pipeline network. Alignment with EN standards provides long-term benefits, including access to European funds and improved system reliability.

7. Conclusion

Energy efficiency of the potable water supply system represents one of the key challenges for modern cities. The analysis of supply points of the distribution water network from the main gravity pipelines in Bihać shows that inadequate regulation of pressure and flow has led to technical and economic problems for end users of the water supply system. It has been established that high pressure at the inlet to buildings not only increases the risk of damage to plumbing installations but also causes additional expenses for households. The implementation of measures such as mini turbines, network zoning, and smart management systems can significantly contribute to a more efficient, sustainable, and user-friendly system. Furthermore, economic analysis indicates that investments in system optimization can result in long-term savings.

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Control of the Pneumatic System for a Rehabilitation Glove

Amila Dedić, Senad Rahimić

Faculty of Mechanical Engineering, University Dzemal Bijedic of Mostar, Bosnia and Herzegovina

E-mail: amila.dedic@unmo.ba

Abstract. Pneumatic components are widely used in modern technical systems due to their ease of implementation, versatility of solutions, and the use of standardized drive components. This paper presents an effective rehabilitation method based on a pneumatic system, designed for individuals who have suffered a stroke or other neurological trauma resulting in hand disability. The rehabilitation glove is an innovative device that enables efficient and early therapy in a very simple manner. The paper provides a detailed explanation of the operating principle of the pneumatic system for the glove, the program that controls the glove, and the way it functions.

1. Introduction

Rehabilitation of hand function after stroke, injury, or neurological damage presents a complex challenge that requires precise and repetitive assistance in performing movements.In recent years, increasing focus has been placed on the development of robotic systems that enable active or passive therapy, with continuous control and adaptation to the individual needs of patients.

Among the various actuation technologies employed in such devices, pneumatic systems have proven to be particularly well-suited for use in rehabilitation gloves. Operating on the principle of compressed air, these systems facilitate smooth and flexible control of finger movements while ensuring low overall device weight and a high level of operational safety. In contrast to electromechanical systems, pneumatic actuators are capable of replicating the natural flexion of human fingers, offering reduced risk of mechanical tissue damage and enhanced user comfort.

These characteristics make pneumatics an ideal choice for applications in medical robotics, particularly in wearable devices that come into direct contact with the human body. Moreover, the simplicity of fabrication and the relatively low cost of materials and components make such systems more accessible for both research prototype development and clinical practice.

This paper presents the design and testing of a pneumatically actuated rehabilitation glove, developed with the aim of assisting patients in the recovery of fine hand motor skills.

2. Rehabilitation Glove

The robotic rehabilitation glove is an innovative device designed for the rehabilitation of a patient's hand following a stroke or other neurological trauma. The most affected neurological domain in stroke patients is the motor system [1]. The hands are the most vulnerable limbs, exhibiting a high rate of disability after various injuries or strokes.

Research conducted to assess the needs of patients post-stroke has shown the existence of a so-called "golden period" for hand function recovery, typically occurring within the first three months after the stroke. Rehabilitation therapy can significantly facilitate the recovery process.

It enables improvement in motor functions and restoration of hand strength through repetitive, identical movements of the impaired hand, as the brain reorganizes itself after the stroke to restore function. Repetitive active training based on tasks requiring finger flexion and extension can restore the ability to grasp and manipulate objects with the affected hand [2].

Table 1 [3] presents a comparative overview of popular systems designed for hand rehabilitation. Both passive and active systems are categorized into subgroups based on their force/torque transmission mechanism.

Table 1. Review of hand rehabilitation system

	Force transmission	System	Developer	DOF	Actuators	O/p force, Torque	Remarks
CPM	Linkage	HandSOME	Brokaw et al.	1	Passive	4 N m	Apply extension torques to cope flexor hypertonia
	Cable	WaveFlex	Otto Bock	1	DC motor	42 N (reversing)	Full composite fist flexion
Active Exo.	Linkage	HWARD	Takahashi et al.	3	Pneumatic	15 N	Assistive
Systems		Rutgers Master II	Bouzit et al.	4	Pneumatic	16.4 N	Direct-drive actuators are located in palm
		Hand Robot Alpha-II	MIT	1	Brushless DC motor	120 N	Fingers move together
		HEXORR	Schabowsky et al.	2	Brushless DC motor	0.13 N m	CPM/Active Exo
		IntelliArm	Ren et al.	1	DC motor	2.5 N m	Single DOF for hand
	Cable	CyberGrasp	Immersion Inc	5	DC motor	12 N	Used with CyberGlove
		Salford Univ. Exo	Sarakglou et al.	7	DC motor	20 N	VR based exerciser
		TU Berlin Exo.	Wege et al.	4	DC motor	?	Actuators reside on-ground
		HANDEXOS	Chiri et al.	5	DC motor	?	Underactuated reside on-ground

The rehabilitation glove enables effective, early, and flexible neuromotor therapy. It can be used on both hands during the rehabilitation process and requires approximately three minutes to be properly fitted and ready for task execution. The glove is actuated by bellows-like tubes located on the back of the hand and along each finger. By increasing the air pressure in the tubing system, a compressor applies gentle pressure to the fingers, causing them to bend, which is shown in figure 1.

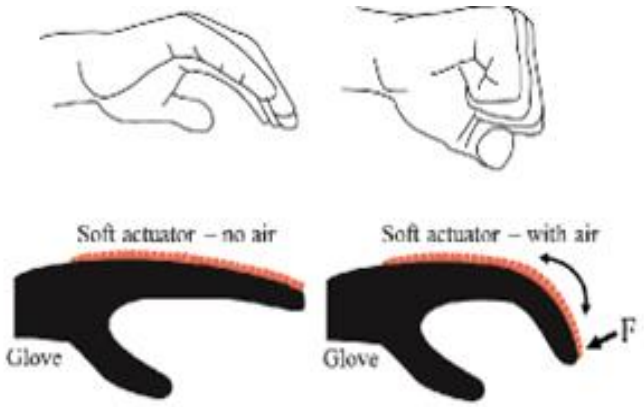

Figure 1. Finger position [4].

The use of the glove does not cause pain for the patient, and in the event of any malfunction, the glove can be easily and safely deactivated.

In order to develop an efficient hand rehabilitation system, it is essential to meet a specific set of structural and functional requirements that enable proper execution of therapeutic exercises. A key component of the system is the set of flexible pneumatic tubes, whose mechanical properties must allow for curved bending that conforms to the anatomy of human fingers in a closed-hand position. The human

hand can be modeled as a serial RRR mechanism with three rotational joints, fixed at a single point. This configuration enables accurate imitation of the natural motion of the fingers. The entire mechanism is positioned on the dorsal side of the hand, leaving the palm and fingertips free for interaction with the external environment.

The integration of actuators into the glove structure must be designed to allow the user to easily and quickly put on and remove the device, with the additional capability for rapid detachment in emergency situations. To ensure universal applicability of the device, an adaptable or adjustable design must be provided to accommodate various hand sizes. The total system weight must be limited (below 500 g) in order to minimize any negative impact on the user's range of motion. Furthermore, the system must not pose a mechanical constraint to spontaneous finger movement when unpowered, which requires a thin and flexible structural profile.

Functionally, the system should enable at least ten flexion-extension cycles of the fingers per minute. Flexion is achieved through pneumatic actuators—flexible tubes that, under the influence of compressed air, change shape by bending toward the non-extensible layer, thereby inducing finger flexion. Releasing the pressure results in passive finger extension, which enables the full range of hand opening and closing necessary for functional rehabilitation.

2.1 Components of the Rehabilitation Glove

The rehabilitation glove features a complex design composed of multiple interconnected elements, each essential for the proper functioning of the glove and the effective rehabilitation of the patient. The primary components of the rehabilitation glove include:

- Distribution network
- Bellows tubes

2.2. Bellows tubes

Bellows tubes represent one of the most complex and critical components of the entire project, as they directly influence the functionality and reliability of finger movement. Their fabrication requires careful selection of materials that must meet two key criteria: high flexibility and sufficient mechanical strength. The tubes must be flexible enough to allow natural finger bending when filled with compressed air. At the same time, the material must not be overly stretchable, to prevent uncontrolled expansion or inflation under pressure, which would reduce actuation efficiency. Instead, the goal is for the bellows tubes to contract or extend linearly under pressure, generating the desired mechanical displacement that mimics finger flexion. This balance between flexibility and structural integrity is essential for the proper operation of the pneumatic system and the safe use of the glove.

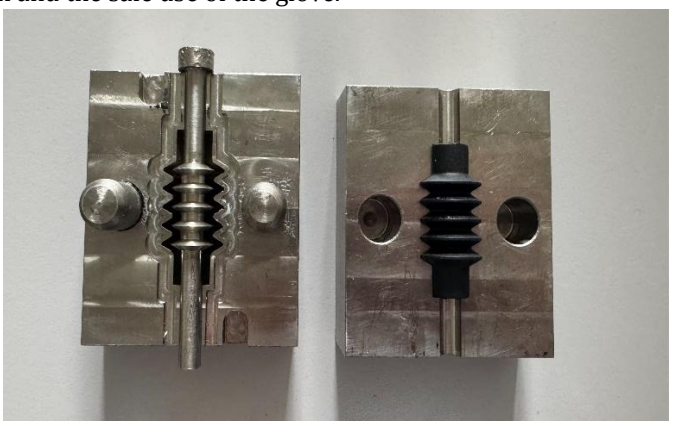

Figure 2. Tool for manufacturing bellows tubes.

A specialized tool was developed for the fabrication of bellows tubes, enabling precise shaping through the process of molten rubber injection molding, which is shown in figure 2. The process begins with heated rubber being injected into a mold using an injection molding machine. Once the material cools and solidifies, the mold is opened, and the formed bellows tube is removed.

During the research and development process, several types of rubber were tested, and the most suitable for this application proved to be rubber with a hardness of 60 Shore, offering an optimal combination of elasticity and resistance to pressure-induced deformation.

The tool for fabricating bellows tubes consists of two main segments. The first part is made of aluminum and comprises two symmetrical halves that form the outer shape of the tube. Inside this section are precisely shaped channels that allow the flow of rubber during the injection molding process. The second part of the tool is made of steel and is inserted into the aluminum segment; its function is to define the inner contour of the bellows tube. A key parameter in this assembly is the clearance between the steel and aluminum parts, as it directly determines the wall thickness of the finished rubber component.

One of the challenges in the manufacturing process arises during the removal of the molded rubber from the tool. Specifically, the steel insert often becomes stuck inside the rubber due to strong adhesion and contraction during cooling. To overcome this issue, a high-powered compressor is used to inject air into the bellows tube, generating enough pressure to safely and efficiently release the steel component from the rubber without causing any damage.

3. Control of the pneumatic glove

The rehabilitation glove is operated via a mobile application that utilizes artificial intelligence, specifically machine learning. The advantage of AI-powered applications lies in their ability to improve and evolve by processing data, learning from it, and thereby enhancing their performance over time. The mobile application controls the rehabilitation modules through synchronized operating modes of the glove via an Arduino control unit. Hardware diagram of the rehabilitation glove is presented in figure 3.

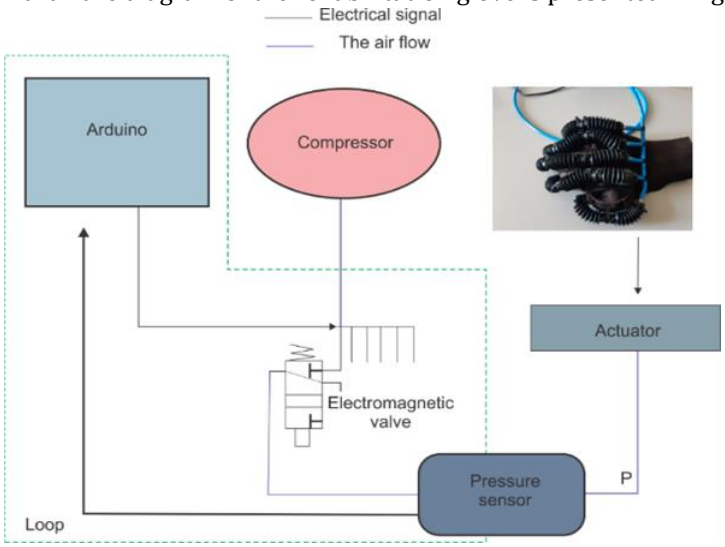

Figure 3. Hardware diagram of the rehabilitation glove [5].

The connection between the Arduino microcontroller and the Android application is established via Bluetooth. The HC-05 is a Bluetooth module designed for wireless communication and can operate in either master or slave mode. It uses serial communication to interface with devices and communicates with the microcontroller through the serial port. In the case of the pneumatic rehabilitation glove, the HC-05 Bluetooth module plays a crucial role as a communication bridge between the Arduino.

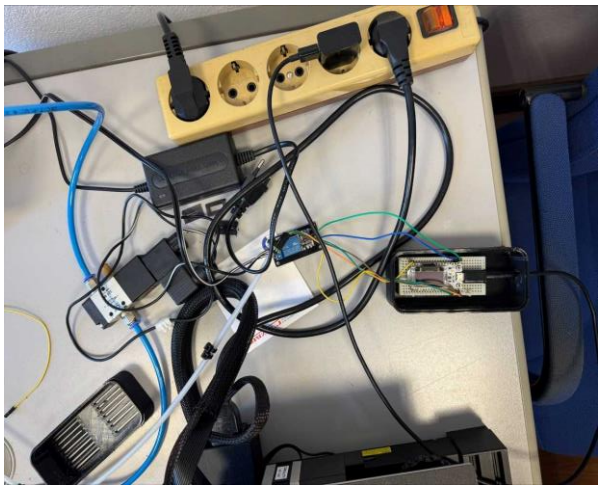

Figure 4. Control components of the rehabilitation glove.

Figure 4 shows the components used to control the pneumatic glove. The pressure sensor detects and measures air pressure and converts it into an electrical signal that can be further processed. It plays a key role in monitoring and controlling the operation of the system, allowing precise regulation of airflow and maintenance of the desired pressure level. This enables accurate dosing of the force applied to the fingers, thereby preventing tissue overload and increasing the comfort of the therapy.

The solenoid valve operates by using an electrical signal to activate an electromagnet, which moves an internal piston to open or close the airflow. In the context of rehabilitation devices, solenoid valves enable precise and rapid control of compressed air delivery to the actuators, synchronized with feedback from pressure and position sensors. Their compact size and fast response make them ideal components for use in portable, soft robotic systems such as rehabilitation gloves.

Figure 5 shows a function used in the Arduino code to check pressure values. This code segment pertains to the situation when the device is connected but the application is not. In this case, pressure values are displayed in the IDE console. If the compressor is not running, the measured value corresponds to atmospheric pressure. In the application, the maximum pressure is set to 1.85 bar.

```
if (deviceConnected) {
   if (akt == false) {
     sensor.read();
     int pritisak = sensor.pressure();
     if(abs(pritisak)>2500)
     {
       pritisak=zadnjiPritisak;
     }
     pCharacteristic->setValue(pritisak);
     pCharacteristic->notify();
     zadnjiPritisak=pritisak;
     //value++;
     delay(1000);

     Serial.print("Pritisak zadani: ");
     Serial.println(pritisakZadani);
     Serial.print("Pauza: ");
     Serial.println(pauza);
     Serial.print("Broj ciklusa: ");
     Serial.println(brojCiklusa);
     Serial.print("Broj ponavljanja: ");
     Serial.println(brojPonavljanja
```

Figure 5. Arduino function for checking pressure values.

4. Mobile Application for Controlling the Pneumatic Glove

Connecting the system to the application greatly simplifies the use of the glove itself. After placing the glove on the hands of multiple patients, a single operator can simultaneously monitor and adjust the operating modes for each glove in use at that moment.

Once the rehabilitation glove is fitted on the hand and the Android mobile application is launched, the first step is to establish a Bluetooth connection. After the application is connected, the following data must be entered:

- Patient's name
- Number of grip and release cycles
- Number of grip and release repetitions within one cycle
- Duration of the pause between repetitions
- Pressure applied during the hand grip

Figure 6 displays the following data:

- The number of cycles is set to 2, meaning the glove will perform two cycles of gripping and releasing the patient's hand, with the selected number of repetitions, in this case three.
- The number of repetitions is set to 3, meaning that within each cycle, the patient's hand will be gripped and released three times.
- The pause between repetitions is entered in seconds and represents the time interval between two consecutive repetitions, which in this case is 1 second.
- The pressure is set by moving the slider on the dark horizontal bar below the pause setting. Here it is set to 18.5, which corresponds to 1.85 bar. The pressure value selected in the application is read by sensors embedded in the glove.

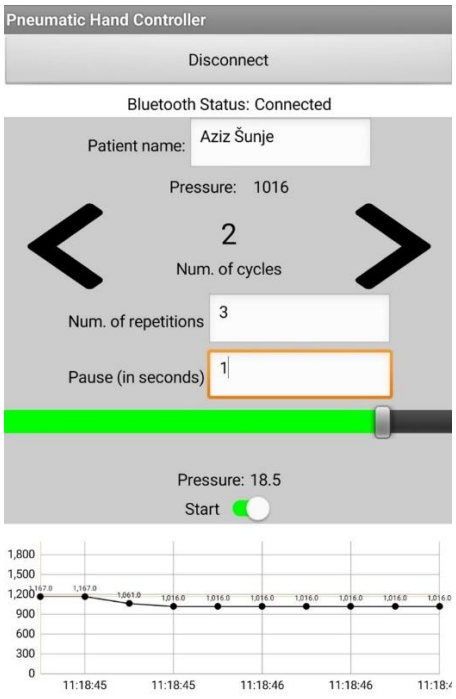

Figure 6. Mobile application for the rehabilitation glove [5].

After all necessary parameters are set, pressing the start button initiates the execution of the selected modes. The data read during operation is automatically sent to the computer, where information about the

patient, usage time, and pressure values can be viewed. Based on the collected data, charts can be generated to clearly display pressure variations, as shown in figure 7.

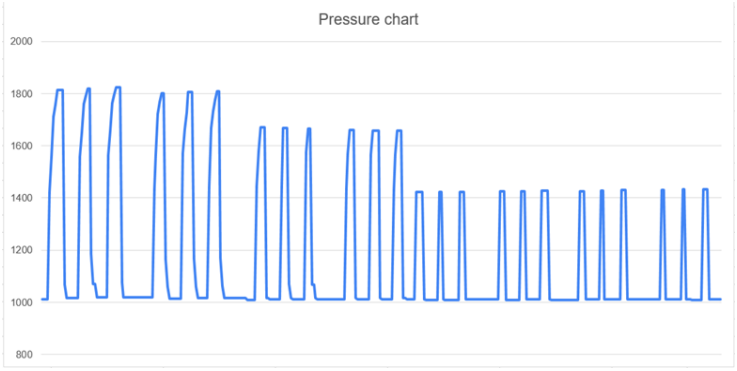

Figure 7. Diagram created based on the data.

4.1 Web application for administration of the pneumatic glove system

Within the management application for the rehabilitation glove, a module has been developed to provide doctors with complete insight into the therapy process and patient progress. The application is intended for medical supervision and is used to monitor all exercises performed by the patient using the glove. Through an intuitive user interface, the physician can review the frequency and accuracy of exercise execution, the duration of each session, as well as the achieved range of finger movements.

Data is automatically recorded and visualized in real time, enabling continuous monitoring of therapeutic outcomes. Based on this information, the doctor can individually tailor the rehabilitation plan, make decisions about the intensity and type of exercises, and promptly respond to any deviations from the expected progress. The application thus represents a crucial link between the patient and medical specialist, ensuring a more efficient, safer, and personalized approach to therapy. Additionally, if needed, the application offers an option for online video calls between the patient and doctor to facilitate better communication and analysis of the patient's finger flexion and extension progress. Furthermore, the physician has comprehensive insight into all patient data, enabling informed decision-making, timely adjustments to the therapy plan, and a more proactive approach to addressing any complications or lack of progress. This is illustrated in figure 8, which shows the interface used by the doctor to monitor patient progress and access detailed rehabilitation data in real time

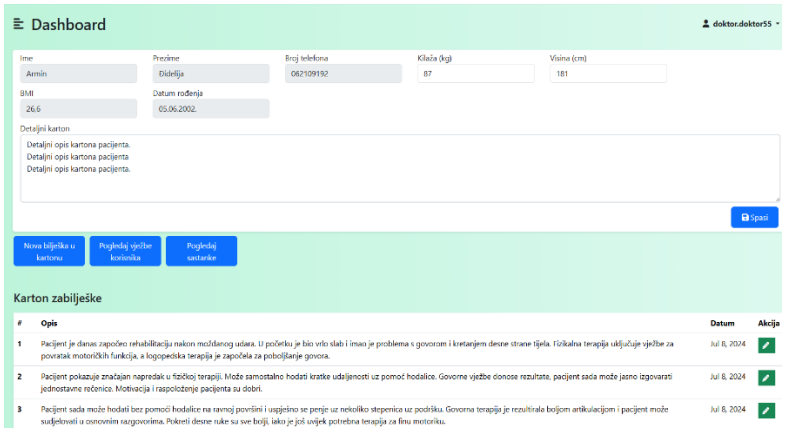

Figure 8. Patient data display available to the doctor.

5. Conclusion

This paper presents the development and fabrication of a prototype pneumatic rehabilitation glove designed to assist with finger flexion during therapeutic hand recovery. The focus was placed on the

manufacturing of bellows tubes as a key system component, investigating various materials and fabrication methods to achieve an optimal balance between flexibility and strength. The use of pneumatic actuation enables a safe, lightweight, and efficient application, representing an advantage over more complex electromechanical systems. Additionally, a web application was developed for administration purposes, allowing doctors to assign exercise regimes to patients and monitor their progress during therapy. Pressure sensor data is obtained via a mobile application used by the patient, connected through the IP protocol. Conducted tests demonstrate that the glove meets the fundamental requirements for rehabilitation functionality. The pneumatic system enables repeated exercise cycles, with a measured force exerted by the rehabilitation glove reaching 17 N, as recorded by the pressure sensors.

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Self-adjusting movable joints of building structures

Majudin Muratović

"Džemal Bijedić" University, Mostar, Bosnia and Herzegovina

E-mail: majudin.muratovic@unmo.ba

Abstract: To the purpose of making construction faster and more economical, in the last few decades, humans have transitioned to an industrialized method of building by using structures made of prefabricated reinforced concrete elements. In addition to the requirement that such structures meet the load-bearing capacity and stability of the construction itself, they should also have sufficient capacity to absorb the energy of horizontal wind forces or the energy introduced into the system by the displacement of supports caused by an earthquake. Energy absorption through section plasticization is possible in structural elements or in the joints of structural components (such as frame nodes), so these elements should be designed to withstand a certain number of alternating plastic deformations without significant loss of load-bearing capacity. In frame structural systems, theories and calculation methods have been developed to ensure controlled plastic deformation. In prefabricated reinforced concrete structures, there are methods for predicting plastic deformations in the joints of structural elements exposed to potential earthquake effects, which are mainly based on experimental results. For these reasons, it is useful to experimentally examine the response of prefabricated reinforced concrete structures under elastic and inelastic deformations caused by horizontal forces. In this way, based on experimental data, an analytical model is established that can be used in the design of such structural systems.

1. Introduction

In all prefabricated systems, special attention must be given to the connections between structural elements. Prefabricated structures are systems assembled on-site using pre-manufactured elements produced in a factory. For this reason, the connections between elements become critical points. This is especially important for structures located in seismic regions, where the performance of these connections should be thoroughly examined.

It is proposed that in the event of a high-intensity earthquake, connections, as critical points, play the most significant role in absorbing energy from horizontal forces acting on the structure. Therefore, an analysis of the ductility and load-bearing capacity of the connections must be conducted through testing and numerical analysis to verify the overall structural safety. For these reasons, special attention must be given to the design and construction of element connections. Testing can determine the characteristics of the connections in terms of deformation, displacement, and load-bearing capacity.

This paper presents an approach to determining the ductility and safety of the proposed connection based on experimental results. The connection should be designed to facilitate the joining of various construction elements, such as walls, panels, beams over openings, columns, and similar structural components. A bolt is proposed as a suitable connecting element due to its simple construction and ease of assembly, making it applicable for this type of structure.

In the case of incident loads or earthquakes, stresses approaching the material's ultimate elongation limit, as well as plastic deformation (stretching) of the bolt body, may be expected. The connection should be designed to absorb energy through its displacement during an earthquake while continuously transmitting forces under alternating loads. The hysteresis loop of the connection should exhibit minimal variation in area during such loading. Testing will determine the force-deformation relationship of the connection and assess the proposed self-adjusting bolted connection. Based on experimental results, a numerical model can be developed for computational analysis of structures using these types of connections. The proposed bolted connection can be easily replaced after exposure to incident loading.

With this type of connection, damage during an earthquake is expected to be localized at the joint without compromising the overall safety of the primary structural system. Experimental testing and numerical analysis can further contribute to the development of structural elements incorporating this proposed connection type. Beyond its application in prefabricated systems, this connection method is also highly suitable for the repair and strengthening of existing structures due to the ease of replacing bolts as connecting elements.

For all these reasons, conducting such experimental studies is necessary to ensure the load-bearing capacity and ductility of the connection. This, in turn, enables the advancement of construction systems using prefabricated elements with this and similar types of connections.

2. Methods of calculation and design of reinforced concrete prefabricated structures

2.1 Theoretical Assumptions

Scientific and technological research, especially in the last fifty years, has enabled the realization of safe, rational, and usable reinforced concrete structures. The characteristic feature of this development period is the industrialization and prefabricated method of construction.

Prefabricated reinforced concrete structures are more suitable for building projects within a short time frame. The construction process of a building is reduced to the production of prefabricated structural elements in the factory and their assembly into a monolithic whole on-site. The advantage of this construction method is that work can be carried out even in winter, significantly shortening the construction period. Due to the industrial production of concrete and elements, material and work costs are reduced. Prefabricated construction is applied to building structures and industrial objects, as well as those that include fewer standard elements.

Since the discovery of reinforced concrete (mid-19th century), monolithic structures of different structural systems, built directly on-site, as well as monolithic frame structures, have been constructed. With this material and construction type, rigid, non-deformable joints can easily be achieved.

Prefabricated reinforced concrete structures began to be used more widely after World War II in our environment. The primary requirement posed to engineers was that the manufacturing and assembly of elements, along with joint construction, should bring this type of structure closer to the characteristics of monolithic concrete structures.

Reinforced concrete frame structures, whether built on-site or from prefabricated elements, should be designed not only to meet load-bearing requirements but also to possess the ductility necessary to absorb the effects of horizontal forces, as stipulated by relevant regulations [1][2].

Previous studies of monolithic reinforced concrete frames have already shown their good performance under the influence of gravitational and horizontal forces. Recently, research conducted in New Zealand has shown that frames made of prefabricated elements, rigidly connected to each other, also exhibit good response under vertical and horizontal forces if designed and constructed properly. According to these studies, connections between prefabricated elements must be made outside critical areas (positions of plastic hinges), so that they remain within the elastic deformation zone. By connecting the reinforcement of elements through overlap or welding, and concreting the joints on-site, continuity of the system is achieved. In this way, the structure behaves as a monolithic construction fully built on-site. Such a joint and other sections of elements, located outside critical zones, must be dimensioned according to the bearing capacity of sections in the plastic hinge area. When joints are made in critical zones, due to the poorer hysteresis characteristics of the joints obtained through experimental research, the expected seismic energy absorption will not occur. Therefore, UBC (Uniform Building Code) and ENV 1998 standards of the European Union [3] predict a reduction in seismic forces through ductility coefficients or response factors. Consequently, the advantage of prefabricated constructions would be annulled or, at best, reduced.

Current research in the United States, under the name “Seismic-Resistant Prefabricated Construction Systems” (PRESS), aims to offer designers a new philosophy for calculating reinforced concrete frames made from prefabricated elements. This method is called the “Inter-story Drift Selection Method,” which is particularly suitable for prefabricated frame constructions with ductile joints, or joints in critical zones. The

basis of this construction method is that seismic energy absorption, depending on the hysteresis characteristics, is directly and simply incorporated into the calculation process.

2.2 Experiment description and numerical analysis

When selecting a model for testing the connections of construction elements, control over the deformations in prefabricated constructions is possible. The "Inter-story Drift Selection Method" was considered as an approach to solving the problem of dimensioning reinforced concrete structures made from prefabricated elements. The paper proposes a model for the connection of prefabricated elements, which underwent deformation and displacement tests. The model represents a part of a reinforced concrete prefabricated structure [4]. Cyclic loading of the connection under tension-compression without shear force between two construction elements was tested on the model. The connection is secured with a specially designed bolt. Through quasi-static testing, i.e., by applying alternating tension and compression forces on the connection, the deformations of the connection, and the bolt as the connecting element, were obtained. The bolt has a smaller cross-sectional area than the reinforcement in the reinforced concrete section of the joint, ensuring that the construction material stays within the linear deformation zone of the reinforcement. The assumption "stronger reinforcement – weaker bolt" had to prove that during the loading process under dynamic conditions, the bolt would absorb the inelastic deformations, while the reinforcement and material of the connection element remain within the elasticity zone.
Most of the energy from the applied load should be absorbed by the bolt of the connection, which, after the load's effect, could be easily replaced, with minimal or no damage to the structure. In this way, the structure remains functional for accepting additional loads. Numerical analysis showed that the system's construction, in the case of a reinforced concrete prefabricated wall with bolt connections of increased ductility, was superior in comparison to a monolithic reinforced concrete wall of the same cross-section.

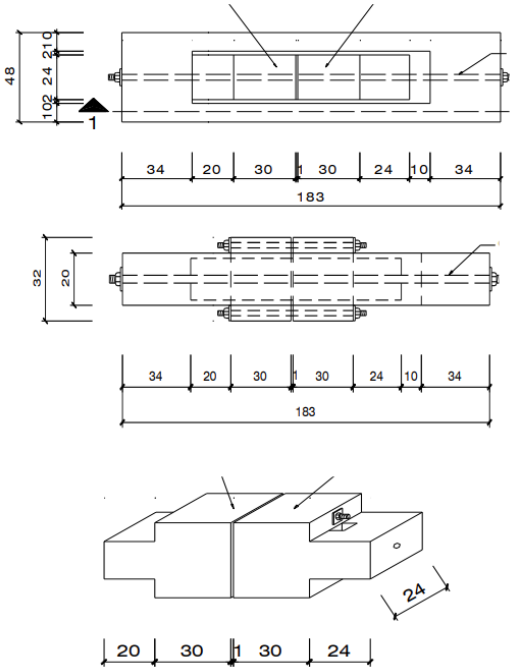

Figure 1. Base, cross-section and layout of the connection model.

During the experiment, the idea emerged for the bolt to be self-adjusting. In this case, the bolt stays within deformation of the same direction (tension). By using counterweights through a wire wrapped around the bolt nuts, conditions were created for the bolt to absorb additional (tensile) deformations during each subsequent load cycle. The experiment confirmed that after each unloading cycle, the nut would rotate on the bolt, nullifying the elongation caused by plastic deformation in the previous cycle. This

confirmed the self-adjustment of the bolt. This created conditions for further analysis of this type of connection and the potential development of a special self-adjusting (mechanical or electronic) bolt system. The bolt can be replaced during the service life of the reinforced concrete prefabricated structure if it is damaged due to plastic deformation caused by wind, earthquakes, or other high-intensity loads.

Here, it should be pointed out the quality testing of the bolts after the experiment yielded values indicating that the steel used for manufacturing the bolts is of slightly better quality than originally assumed. Unlike the assumed quality of smooth steel GA, which has a yield strength of 240 MPa and a tensile strength of 360 MPa, the obtained values for yield strength were 320 MPa and tensile strength 480 MPa. These stress values, for the given cross-section of the bolt, correspond to tensile forces of 36 kN and 54 kN, respectively. For these obtained values, the following deformation characteristic diagrams of the connection were made, which refer to the cyclic application of tensile and compressive forces.

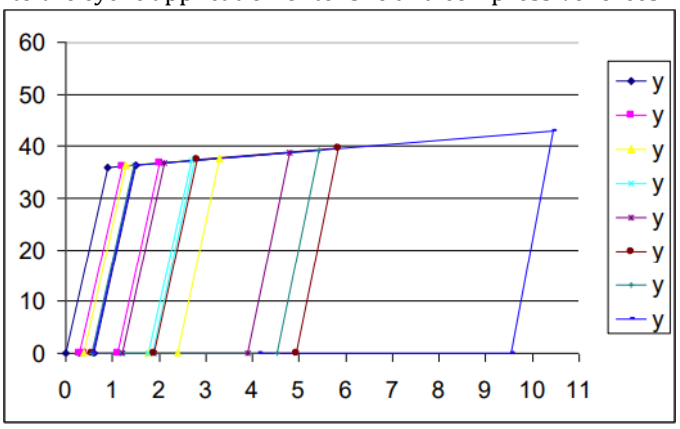

Figure 2. Deformation of the connection after cyclic testing.

2.3 Comparative analysis of the expected deformations and displacements of a precast reinforced concrete wall connected with GA 240/360 quality bolts and the corresponding cast-in-place reinforced concrete wall

The analysis showed the response of a 7-story reinforced concrete wall with bolts as a connecting element in the joints. A higher level of ductile response of the wall was demonstrated compared to a wall of the same dimensions made monolithically.

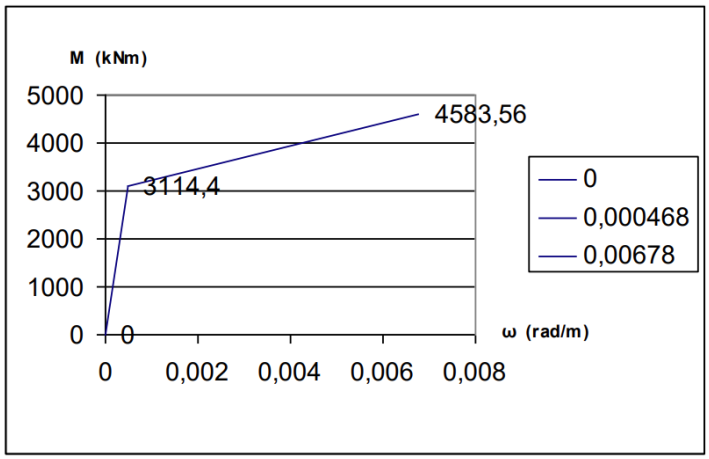

Figure 3. The values of bending moments at the critical cross-section as a function of the rotation of the cross-section at the yield and fracture limits.

This has shown that for the section at the connection with the foundation, the moment from the external load (M = 4178,4 kNm) is within the range between the values:

M^Y = 3114,4 kNm

M^U = 4583,56 kNm

i.e., between the bending moments at the elastic limit and the ultimate moment at the breaking point that the reinforced concrete section can withstand. This causes the section to enter the area of plastic deformations, which is desirable when designing structures for seismic effects because this way more energy, accumulated by the action of significant horizontal loads during an earthquake, is dissipated.

The values of the moments in the sections above the reinforced concrete slab of the first floor up to the top of the structure are lower than the moment at the elasticity limit.

It has been shown that the sections of the reinforced concrete slab on the first floor undergo plasticization, while the sections above the first floor remain within the elastic deformation region. This approach aims to dissipate seismic energy introduced into the structure through the plasticization of bolts as connections, ensuring that pressure stresses in the concrete do not exceed the allowed values, i.e., preventing permanent damage to the structure. This approach to designing seismic-resistant structures aligns with new trends in earthquake engineering, where controlling the formation of plastic zones in buildings is a key focus. After the earthquake, the bolts in the connection can be replaced, allowing the structure to once again take on new loads.

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Application of technical vibrodiagnostics in the context of predictive maintenance of industrial machines

Sarajko Baksa[1*], Ines Baksa[2] and Andrej Marić[3]

[1] Međimurje Polytechnic in Čakovec, Čakovec, Croatia
[2] University of Applied Sciences in Security and Safety, Zagreb, Croatia
[3] Ferro-Preis d.o.o., Čakovec, Croatia

[*]e-mail: sarajko_baksa@yahoo.com

Abstract. Scientific research was conducted when using application of technical diagnostics and vibrodiagnostics, when testing and analysis of vibrations and stresses of the machine tool with diagnostic device, on example of automatic industrial grinding machine of grey and nodular castings (Koyama). Basic goal of this research was measuring and analysis of vibration of the machine and determination of tool stresses during cutting and grinding cycles. By means of diagnostic device Fixturlaser SMC, were analysed key characteristics such as: speed vibration, acceleration and balancing of the main circular. Furthermore, the paper emphasizes importance in protective maintenance for the prevention of origin of damage and increase efficiency, as well as preservation of the workers' health. Also are explained theoretical basics of vibrations, methods of measurements, and analysis and data processing by using contemporary diagnostic tools. Shown practical results were done through measurements on casting model 21005034, including technical description of the machine, tools, and diagnostic devices. In conclusion, the research emphasise application of technical vibrodiagnostics in context of savings, reductions of standstill and faults, as well as increase in productivity.

1. Introduction

Vibration analysis i.e. tracking of vibrations has recently become indispensable and most reliable method of mechanical engineering diagnostics. Diagnostics itself access departs from the fact that every dynamic and mechanically disorder causes vibrations and stresses of certain type. There is a significant number of developed and implemented methods of vibrodiagnostics, however, it is possible to choose minimal combination of methods by which we will discover and give maximum detection causes of possible faults, with the benefits of the complete efficiency applications and ease of use, and fast removal of potential breakdowns. It is known that catastrophic failures and malfunctions of machine can cause serious injuries to the employees, it can result in loss of a machine, stopping overall department or facilities through longer period, and what consequently results with unwanted business and economic losses.

The term ''predictive'' refers to the ability to predict future events or conditions based on the analysis of available data. In the context of technical vibration diagnostics and maintenance, predictive maintenance means using data and technologies to monitor the operation of machinery to identify potential problems before they occur. The goal is to increase efficiency, reduce downtime, and optimize maintenance costs. An example of a predictive approach would be a system that uses sensors to monitor the vibrations of a machine. When the data shows unusual changes in vibrations, the system can predict a failure and alert technicians to act before the problem escalates.

2. Technical diagnostics

Term technical diagnostic comes from the word "diagnosis" (*Greek*) which means recognition, assessment, and conclusion. Technical diagnostics is the science of recognizing the work of technical system with the aim of discoveries of malfunctions during operation. With the help of diagnostics status, information of the element's wear and tear is collecting during its usage. The task of technical diagnostics includes determination of the components and equipment states in the time of its exploitation, trial operation or testing. Basics technical diagnostics comprehend analysis of diverse physical occurrence, and on such grounds are making appropriate decisions, as well as decisions further in maintenance, replacement, and equipment or spare parts.

There are two basic shape of technical diagnostics: a) General technical diagnostics for which is still uses the name functional or fast technique; here, the goal is to determine the state of the objects shape by criteria: whether such object is in operation or such object is in malfunction condition, and b) Local technical diagnostic that has a goal towards determination of states and cause of potential possible malfunctions of certain elements in the system. In doing so, there are three stages of possible applied technical diagnostics: a) Monitoring and determination of deviations of diagnostic parameters and signals from their nominal values, b) Character analysis and causes of occurrences of diagnostic parameters deviations and diagnostic signal from the nominal values, c) Forecast of possible operation of the circuit or element without stopping [1].

2.1. Basic tasks of technical diagnostics

Task of technical diagnostics is that the diagnosis that was based on obtained and analysed results of the system we get the real state of the system or their certain elements. By diagnosing it, reliability and efficiency of technical system increases during its exploitative periods.

There are three basic tasks pertained to technical diagnostics: a) Diagnosing – provision of the existing state of the machine, b) Forecasting – prediction of technical state in which the system will be found, and c) Retrospective that is based on the acquired (previous) knowledge and experiences; - a provision that states about the technical system in some former occurrence.

2.2. Technical diagnostics procedure

To recognize the real state of some technical system, technical diagnostic unites theory, methods, and resources. During this very process, for the correct procedure is important to establish diagnosis, which for its purpose has defining the real states system or components.

Correct procedure of technical diagnostics consists of [1,2]:

- setting sensors on existing diagnostic facility,
- stabilization facility operating mode and diagnostic equipment,
- enrolment of diagnosticated states,
- measurement and registration on diagnostic parameters,
- comparison between obtained results,
- finding diagnostic solutions, and
- conclusion on a basis of analysis.

Sometimes are systems which needs diagnosing exceptionally complex what requires large number of parameters, which are inevitably need to determine the real state of the technical system, which consequently effects on additional "spectrum" of diagnostic instruments [3].

3. Vibrations

Vibrations are flickering or mechanical oscillations of (periodic) movements of some system (vehicles, machines, structures...) with small amplitudes. Vibrations are greatly represented in almost all areas of work and industries like mechanical engineering, construction, aviation, shipbuilding etc., where occur periodic movements of bodies with small amplitudes. Vibrations in the context of safe operation of machines and devices are considered harmful and unwanted by appearance, due to all consequently possible mechanical problems which can cause. They influence in a harmful way on machines and constructions, and ultimately on people health, especially in terms of musculoskeletal damage. Definition of mechanical vibration is that every repeatedly movement of the mechanical system about some balanced position, i.e. movement of body of mass "m" which is hooked on a spring with constant "k", see Figure 1. If the body is pull out from the state of equilibrium for the amount “y0“and leave only to oneself, it will move in line with the harmony law:

$$y = y_0 \cos \omega t \text{ ili } y = y_0 \cos \frac{2\pi}{T} t \quad (1)$$

Where ''yo'' is the amplitude, circular frequency "w", time "t" and " T" the time for which body make one full vibration. There are also non-harmonic (deterministic and stochastic) vibrations where the movement takes place according to law different of sinusoidal movements, but can be also periodic, see Figure 2 [4].

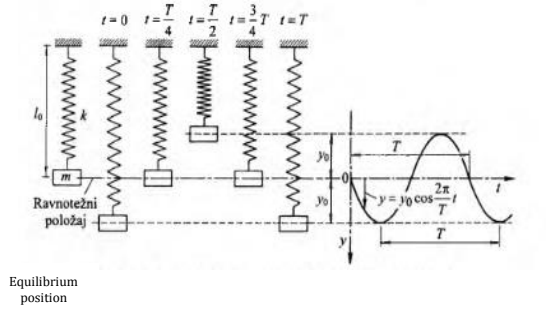

Figure 1. Vibrations od body of mass "m" which hangs on spring of constant "k".

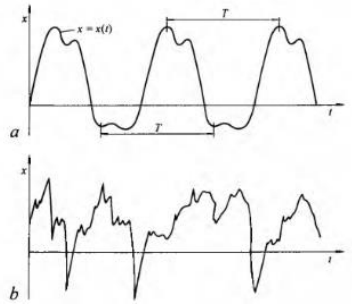

Figure 2. Periodic and non- periodical movement.

Basic division of vibrations: a) Simple vibrations, occur under the influence of harmonic forces. The system is called harmonic oscillator, and the energy in it remains constant. b) Damped vibrations that gradually loose energy, which causes decrease in amplitude and gradual cessation of movements. When the damping is small, the amplitude exponentially decreases with time, and the frequency becomes smaller, and is called frequency muffled vibrations, and c) Forced vibrations that arise when external periodic force system compensates energy lost due to friction, allowing it to continue to oscillate. If the force is correctly coordinated, it can reach resonance, where the amplitudes increase significantly.

The appearance of noise or vibration in working machines can cause stresses in the material which, in turn can cause fatigue or breakage of the machine elements, physiological and psychological interference and disturbance with employees, technological disruptions in work technical system (accuracy in operation. less capacity, smaller efficiency, weaker utilization of tool capabilities, etc.).

4. Maintenance and vibrodiagnostics

Vibrodiagnostics is a method which is used for tracking technical accuracy of the machines by vibration analysis. Application of vibrodiagnostics allows timely detection failures, reduction of maintenance costs and increase of operational efficiency. This technology is especially useful in industrial plants, where unexpected malfunctions can cause big financial losses and to violate the production process. By following states of key mechanical parts, such as bearings, shafts, rotors, and gears, it ensures long-lasting and reliable operation of machines.

For the system of maintenance to be efficient, it is necessary to ensure several organizational prerequisites. This includes existence of professional maintenance services, fast registration of malfunctions, and emergency repairs and rehabilitation of problem before more serious malfunctions appear. Maintenance planning allows control of costs and improves stability production [5]. Correct maintenance of the machines ensures their long-life duration and stable operation. Industrial facilities often use vibrodiagnostics to estimate machines condition before and after overhaul. This method allows defining initial state of the system before exploitation, and with quality analysis after completed repairs. In this way ensures that every mechanical parts function optimally, which reduces the possibility of unplanned failures.

Main maintenance goal includes achievement of maximum productivity, optimization of efficiency and insurance of safety at work. The productivity is continuously achieved by the working machines with minimum stall time, while optimization of efficiency includes economic payable work with the reduction for the repair costs. Safety of the machines are crucial for protection of workers, since the bad maintained machinery can represent serious security risk at work.

Vibration analysis can be implemented through the four main categories: a) Weather domain - the vibrational signal is converted into a wave form and being analysed using oscilloscope, b) Frequency domain - uses spectral analysis for precision determination of the frequency vibration machine, c) Related domains - include advanced analytical techniques, such as the Gabor Wigner transformation, for deeper vibration analysis. d) Modal analysis - benefits computer simulations to predict different shapes of

oscillation for the purpose to gain optimized structure of the machine [6]. Apart from these methods, there are additional mathematical algorithms for vibrodiagnostics vibration analysis. Fast Fourier transformation allows converting time signal in frequency spectrum, which gives detailed insight into the working machine condition. Phase measurement analyses time difference of signal, while resonant analysis identifies natural frequencies system and helps to optimize in operation of the machine.

Implementation of vibrodiagnostics and correct maintenance of industrial machines play key role in increasing operational reliability and maintenance of cost reduction. Regular control of vibration ensures stable operation, reduces the need for expensive repairs, and increases safety at work environment. Considering on ever larger degree of implementation of automation in modern industry, vibrodiagnostics becomes unavoidable for insurance of optimal efficiency of tools and machines, and for the improvement of production process itself.

Additionally, development of new technology allows for all more precisely methods for the analyses of vibration. Modern sensors and computer simulations help at early discovering of irregularities, which allows preventive maintenance and prevents potential malfunctions well before that lead to the greater problems. By integrating vibrodiagnostics with automated systems maintenance, companies can significantly mark on reduction of operational costs and increase of productivity.

5. Measurements and vibration analysis

Measurements and analysis of vibration are made with the help of the "Smart Machine Checker" Fixturlaser SMC device for vibrodiagnosis, on "Koyama" automatic castings grinding machine with circular and grinding working diamond. Practical example of Fixturlaser SMC usage is in measurement and analysis, such as: speed vibration, acceleration and balancing work that was carried out during working process of cutting and grinding of castings, with the power plant mark 21005034, at 2750 rpm with display and selected places and position for measurements. Wireless sensor is placed sideways on housing bearings, regarding the most loaded parts for housings transmission of an electric motor, see Figures 3 and 4.

Figure 3. Measurements position.

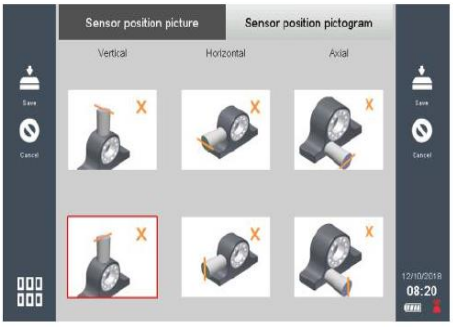

Figure 4. Sensor's position.

On Figure 5 is shown the measurement of acceleration on three axes (Y, X, Z), and noise produced during work which is on average 135 dB, which is within the normal limits, while average acceleration in all three axes is 5,75 mm/s, and is within tolerance which is 3,5 to 6 mm/s. Furthermore, measurement has shown vibration on all three axes (Y, X, Z), which are divided on: total vibrations, overall accuracy (g-amplitude vibration), and the malfunction coefficient. Based on executed measurements, device automatic evaluates state of the set; see Figures 5 and 6.

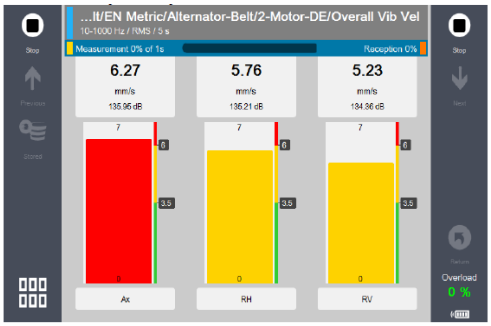

Figure 5. Acceleration and noise measurements (mm/s, dB).

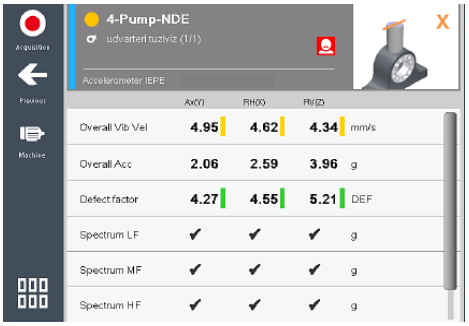

Figure 6. Total vibration measurements.

Vibration analysis is set to variable speed drive frequency of 24,38 Hz measured at 7,5kW motor. Measurement reveals that after starting of engine there was a slight increase in vibration amplitude on all three measurements spots, 0,030 m/s which is also the largest amplitude, while considering the continuous operation in a cycle, amplitude is stable and is 0,012 m/s; once the cycle has reached the end of operation, the amplitude amounts 0,018 m/s, see Figure 7. For balancing rotor seen in two planes, both sensors are used at the same time; when the technical data are obtained, we have: amplitude, phase, and speed in two planes; - see Figure 8. Measurement results indicate that the problem of structural resonant vibration, as shown data has not detected and they do not indicate signs of mechanical problems.

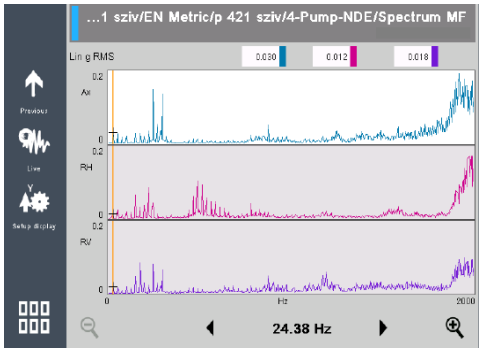

Figure 7. Acceleration, shift analysis and signal speed.

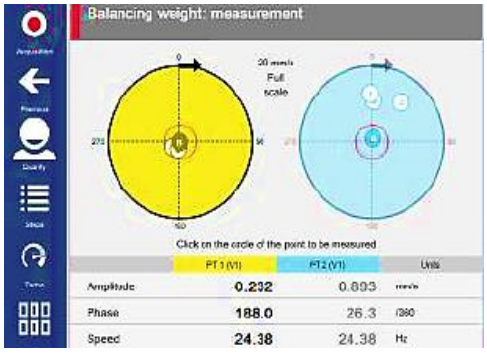

Figure 8. Balancing measurement results.

Vibrations are results of interactions of "imbalance" or imbalances in the coupling of radial acceleration, created due to rotations rotor assembly, what results by appearance of the centrifugal forces. Rotor imbalance occurs while its mass is not at the centre but it is unevenly allocated.

6. Measurements and the results analysis

In Table 1 are shown the measurements values set on a practical example. The vibration amplitude was measured on three axes in five spots. After the measurement, the value of acceleration of the middle vibration amplitude (mm/s) is visible, see Figure 5.

Table 1. Obtained results for the measurements of acceleration.

Measurement axes	***Spot metering***	***Y***	***X***	***Z***
Vibration amplitude (mm/s)	1.	6,262	5,773	5,248
	2.	6,277	5,757	5,226
	3.	**6,274**	5,771	**5,231**
	4.	6,275	**5,764**	5,241
	5.	6,285	5,792	5,234

In Table 2 are listed the results of the noise measurements that was caused by working machine and vibrations. After measurement, maximum value for the visible caused noise amounts of 135,95 dB

Table 2. Obtained results from noise measurements.

Noise	*Measurement time*	*Y*	*X*	*Z*
dB	1.	134,38	134,99	133,09
	2.	134,76	**135,21**	133,17
	3.	135,91	135,04	133,45
	4.	**135,95**	135,02	133,93
	5.	13587	134,86	**134,36**

Furthermore, within Table 3 are shown the measurements in three axes obtained with accelerometer. Measurement includes total vibrations, overall accuracy, and coefficient of device malfunction. Using of the colours (green, yellow, and red) indicates whether they are measured values within allowed tolerance. Green and yellow colour indicate that the components respectively, machine is in good condition, while the red colour indicates on possible errors during operation, see Figure 6.

Table 3. Obtained results from the measurements of total vibration, total accuracy, and coefficient malfunction.

Measurement axes	*Spot metering*	*Y*	*X*	*Z*
Total vibrations (mm/s)	1.	4,95	4,62	4,34
Overall accuracy (g)	2.	2,06	2,59	3,96
Failure coefficient	3.	4,27	4,55	5,21

The results of the measurement of vibrations are shown in the Chart 1. The cycle moves according to measuring steps described in the legend. The graph shows that the amplitude vibration when starting the circular of engine increased by 0,018 m/s and peaked at 0,030 m/s with the first touch, respectively on the occasion when the machine begun to cut inflow of the casting system, where at the same time, were registered the largest vibrations and stresses of the tool itself. The amplitude then stabilizes at the time as the grinding period continues, and falls on oscillating value of about 0,012 m/s. After completion of the grinding cycle, the motor's circular switches off what causes mild amplitude increase on average of 0,018 m/s, and after that it drops to 0 m/s at the engine cut off.

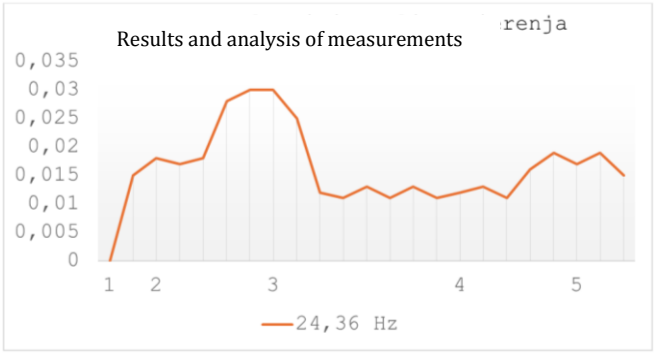

Chart 1. Measurements results and vibration analysis.

Legend:

1) Resting.
2) Switching on engine circular.
3) Contact with the casting i.e. cutting the raw material.
4) Continuous grinding without cutting, and
5) Completion of cycle (terminating of engine circular).

7. Conclusion

By using contemporary diagnostic technology, operational reliability and functional correctness of the machine mechanical parts and devices, everything is getting easier to maintain predictive controls. Timely and periodic diagnosing largely helps prevent created damage to the machine parts, while reduces economic losses, prevents delays or losses of productivity, and ultimately prevents the potential threat to human life caused by the sudden mechanical breakdown. The empirical recommendation is that with the diagnosis and analyses proceeds periodically every 6 months with accessories visual controls and examination of other parts of the machines. Although in this paper modern assessment technology was applied, and prices of diagnostic tools remain significantly high, investment in them is unquestionable given the appearance of all interference and failures that can realistically happen in production.

Original indicators of problems with the working equipment are often vibrations, and their correctly and timely measurement and interpretation plays a key role in maintaining, reliability and efficiency of the working system. With this work are investigated the application of vibrodiagnostics device “Fixturlaser” SMC" as one of the most successful diagnostic tools for detection of vibrations. With its ability for discoveries of high-frequency sound signals passing through stemming from friction and oscillations within the equipment, measuring system provides more significant speed advantages and precision analytics data. With the use of three axial contactless sensor, it is possible to detect irregularities in work equipment, even before the mechanical failure becomes noticeable larger and more dangerous.

Based on Table 1 in which is shown acceleration, measured in three axes, the medium one is visible value of acceleration which amounts for: axis Y = 6,274 mm/s, X = 5,764 mm/s, and Z = 5,231 mm/s. In Table 2 are shown the results from noise measurements along the axes, that display maximum noise level of 135,95 dB. Furthermore, in Table 3 is shown the accelerometric measurement of total vibration, total accuracy, and predictive coefficient of failure.

In accordance with the done measurements and implemented analyses established results it was found that the machine works correctly, without damage and that there is no potential failures which allows predictive in-process diagnostics of technical maintenance that is influenced on: state of performance when ensuring that machine parts work optimally, mechanical longevity and durability and resistance to wear, preventive sustainability in measures that ensure long-term and reliable work, and operational readiness in a state in which parts of machines and devices are fully functional. Consequently, the costs repairs are reduced, as well as it was affected on security and protection of human health.

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Pareto (ABC) segmentation of products within the industrial distribution logistics

Sarajko Baksa[1*], Ines Baksa[2] and Ivan Prelec[3]

[1] Međimurje Polytechnic in Čakovec, Čakovec, Croatia
[2] University of Applied Sciences in Security and Safety, Zagreb, Croatia
[3] Zagreb University of Applied Sciences, Zagreb, Croatia

[*]e-mail: sarajko_baksa@yahoo.com

Abstract. The real-world application of Pareto (ABC) analysis in industrial logistics has been scientifically investigated with a special emphasis on optimizing product flows within the industrial distribution sector. Industrial logistics involves the management of materials, products, and information with the aim of increasing efficiency and reducing costs. Pareto analysis that is based on the "80/20" rule, enables the identification of key elements that contribute most to the positive business results, while ABC analysis classifies products into groups according to their importance; A (high), B (medium), and C (of low priority). The research was conducted in a Croatian company specializing in built-in products for the European automotive industry, in the context of optimizing transport logistics. Prioritized products identification enabled better organization, reduced delivery delays, and increased customer satisfaction. The Pareto diagram provided visual support in technical analysis, while the application of the method significantly contributes to the improvement of the interdisciplinary segment of strategic planning of technical logistics processes.

1. Introduction

Pareto analysis, also known as the 80/20 rule, originated from the Italian economist and sociologist Vilfredo Federico Pareto, who observed that a small number of causes (20%) often generate most of the results (80%). This simple yet universal paradigm has enabled process optimization in a variety of technical and social fields. The application of Pareto analysis in industrial logistics is based on problem solving through the identification of key factors.

Pareto analysis has evolved into a more complex form as ABC analysis, a tool that is used to segment elements according to their importance. This method allows resources and activities to be directed towards those elements that have the greatest impact, giving priority to group "A", while groups "B" and "C" receive medium and lower priority. Within industrial logistics, ABC analysis is used for warehousing optimization, inventory management, supplier analysis, and problem solving in delivery.

With the visual tool of the Pareto diagram, analysis becomes more efficient, allowing the classification of causes and effects according to their frequency and significance. The combination of these tools contributes to a successful strategic management within manufacturing and sales organizations. The Pareto principle of segmentation provides the basis for making decisions that improve productivity and reduce costs, making it indispensable in modern industrial logistics practice.

2. The Pareto principle of segmentation

The Pareto principle of segmentation states that approximately 80% of the results stems from 20% of the causes. As an example, it can be observed that the minority makes up the majority;

- 80% of the world's wealth is owned by 20% of the population,
- 80% of complaints come from 20% of people,
- 80% of a company's profits come from 20% of its customers,
- 80% of a company's sales come from 20% of the products,
- 80% of sales are made by 20% of outstanding salespeople,
- We spend 80% of our time solving only 20% of problems …

Later, in the field of quality control, experts began to express and interpret this principle with the help of the diagrams to solve a problem by breaking it down into several major (highest priority) and several minor (lower priority) problems. In this way, the Pareto principle evolved into a more complex method called Pareto analysis or ABC analysis [1].

2.1. Classification of ABC analysis segments

Pareto or ABC analysis has its application in the organizational, sales, purchasing, development and production sectors. In the field of industrial logistics, it is most often used for the purpose;

1. Analyses of the warehouse regarding the identification of the best-selling products from the warehouse for the purpose of better planning and organization, as well as optimal storage and delivery.
2. Stock analyses regarding the identification of the most important stocks for the purpose of better inventory management and cost reduction while ensuring the availability of the most important products for fast delivery.
3. For the supplier analysis to identify key suppliers that contribute to most of the procurement costs or logistical problems, to improve business conditions and increase reliability.
4. Analyses of problems regarding the identification of the most common problems, such as problems with delivery due to delays, damage, or incorrect delivery, to improve the quality of delivery to the end customer.

A very important tool in Pareto analysis is the graphic display, i.e. the Pareto diagram, (see Figure 1), which is used to realize:

1. Classification of occurrences of causes and effects according to frequency, significance, and importance,
2. Identifying of the most significant problems, and
3. Spotting of the critical area.

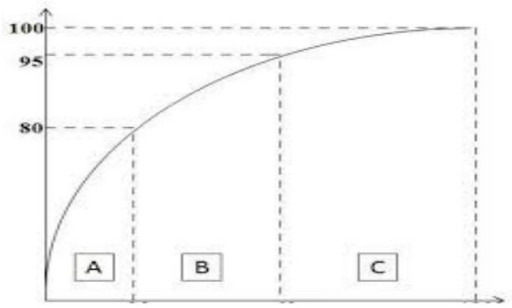

Figure 1. An example of a Pareto diagram [2].

During classification, A group contains group of the highly influential properties and characteristics, while B group contains influential properties, and the less influential properties and characteristics are present in the group C. On this way, boundaries are determined, where group A covers 70-80% of the cumulative amount, group B, associated with group A, covers the next 90-95%, while group C covers the remaining 5-10% of the cumulative amount.

Pareto analysis is carried out as follows:

1. A list of all the causes/consequences of the problem is created, which is investigated in a certain period, the frequency of the causes/consequences of the problem is monitored, and if possible, the related costs.
2. A cause/effect analysis is performed based on frequency to identify the most common problem.
3. Over a longer period, tracking the costs incurred due to these problems/errors.
4. Creating an error analysis by incurred costs to identify errors that cause the highest costs.
5. For the errors that occur most often, the cause is sought and corrective measures are proposed to eliminate them.
6. For errors that cause the highest costs, it is suggested to reduce or eliminate them, if possible.

7. Since the errors that occur most often and cause the highest costs have been identified, the priority of corrective activities is determined.

ABC analysis is a generally applicable procedure and therefore has a wide range of applications. It is used in sales (ABC customers) and materials management (ABC materials, ABC suppliers) as well as in cost accounting (ABC fixed/variable costs) and controlling (ABC resources). This method is even widely used at the organizational (ABC processes) and management level (ABC urgency, ABC importance). ABC analysis is of immense importance, especially in materials management, because it can be combined with XYZ analysis. Both analyses together, both Pareto and ABC analysis, are important tools for evaluation, quality, and control of the overall production process [3].

3. Logistics processes of modern industrial production

The strategic importance of logistics processes in the business of a company, and especially in the supply chain, is one of the most importance. Organizations with efficient logistics features are more productive and competitive, because they can reduce their operational production costs and offer better quality service to their customers [4].

With the consolidation of new consumer norms such as multi-channel retailing, competent logistics management often means having a competitive advantage. In this regard, more and more companies are focusing on implementing modern, new technologies that provide to the end customers efficient and timely service with minimal downtime and errors.

Logistics processes encompass all activities through which a product or built-in product passes from production to delivery. This includes: material supply, production chain, transportation, storage, and distribution. The goal is to deliver quality, the required quantity at the right time and in the right place at a pre-agreed price.

A fundamental postulate in an optimized supply chain is the firm management of all activities involved in various logistics processes. Companies must ensure that resources and information are properly distributed across all segments within their logistics processes. The five most common logistics processes are: a) procurement, b) warehousing, c) inventory management, d) commissioning and shipping (process of processing orders), and e) transportation and delivery of goods, as can be seen in Figure 2.

a) The purpose of procurement is to supply raw materials or goods to a logistics centre, production centre or sales point for the purpose of proper business operations (production, distribution, or sales). The realization of a well-organized and coordinated production facility is essential for managing procurement in an efficient and profitable manner. Companies that incorporate a warehouse management system into their logistics processes can organize their inventory levels based on their procurement strategy.

b) Warehousing includes activities related to the proper storage, protection, and preservation of goods for the required period. To perform this activity, a company must choose a storage system that best suits to its logistics needs, considering the layout of the facility and the characteristics of the products themselves. It is important to choose the right number and type of handling equipment for handling products. Manufacturing companies use automated solutions, such as: stacking cranes, conveyor belts, electrified single-track systems and transfer vehicles, among others, to increase productivity and reduce errors, see Figure 3.

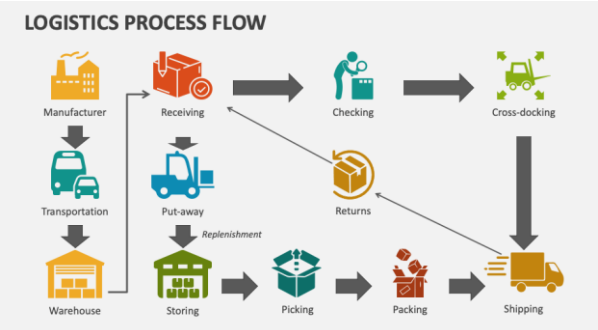

Figure 2. Pictorial representation of the flow of logistics processes [5].

Figure 3. Flow-through storage pallet racks with push-back system [6].

c) An effective logistics process of inventory control and management has a direct impact on the throughput of technical production activities involved in the logistics process and reduces exposure to overstocks or understocks.

d) Commissioning and shipping (order processing) includes product packaging, so that they can be sent with minimum costs and in the shortest possible time. Together with transport, this logistics process has a significant impact on the satisfaction of the end customer. Commissioning and shipping jobs include various activities that include: circulation of operators in the warehouse, removal of products from the racks, sorting and consolidation of goods, packaging and loading onto the lorry.

e) Transportation and delivery, as the final stage of the process, are significant challenges in technical logistics. Products must overcome obstacles from the moment they leave the distribution centre to their destination. Optimizing costs is crucial for efficiency and competitive differentiation. In this phase, companies usually cooperate with transportation agencies. To avoid delays and breakdowns that lead to complaints and slow business growth, they must coordinate packaging and labelling processes with carriers and forwarders [7].

4. Conducting of the research

Within this research work, a logistics study was led on the example of a Croatian company, which manufactures parts for the automotive industry, in order to help, or rather facilitate the selection of the appropriate mode of transport to the end customer, because so far all products have always been sent in the same way, without priority, which consequently in a large number of cases results in delivery delays, receiving damaged products, what finally results in dissatisfied end customers. The analysed manufacturing company was in a dilemma about which products should be transported in a way that the shipment is sent by standard means, as before, without insurance and the need for additional express delivery costs, or that it should be sent to the end customers as quickly as possible, as a priority shipment and with additional insurance costs.

To scientifically determine what was previously said, Pareto/ABC analysis was applied on a part of the products which are used to classify products from the warehouse and segment them into one of three groups: A (highest), B (medium) and C (lowest priority).

In the first step, a table with products is created, where the annual demand, unit price of the product, and the total value and total sum of income are presented, as seen in Table 1.

Table 1. Product classification.

	Annual demand (piece)	**Unit price (€)**	**Value (€)**
TPMS valve (sensor)	832	40.00	33,280.00
Centering ring	2080	4.00	8,320.00
Screw M14x1.5	1040	3.00	3,120.00
Screw M12x1.25	520	4.00	2,080.00
Distance (spur expander)	624	20.00	12,480.00
			Σ = € 59,280.00

During the second step, the order of the products is changed with respect to their value, and they are positioned in the sequential table from the highest to the lowest value, as it was shown in Table 2. After which the table in question is supplemented with the two columns expressing the share and cumulative share in the total value, in accordance with expressions 1 and 2;

$$\text{Share in total value} = \frac{\text{Individual value of the product}}{\text{Total value of all products}} \text{ x } 100\ (\%) \quad (1)$$

$$\text{Cumulative share}_{n} = \text{Cumulative share}_{n-1} + \text{Share}_{n}\ (\%) \quad (2)$$

The cumulative share in the expression 2 adds up the shares of individual products step by step to obtain the total share for each product in the series. For the initial product, the cumulative share of the first product is equal to that product's share of the total value; for each subsequent product, the cumulative share for the current product is obtained by adding that product's share of the total value to the cumulative

share of all previous products. This process is repeated for each subsequent product until all shares reach in total 100%. This is used to track the distribution of values or quantities, step by step, until the entire data set is covered.

E.g.: If the first product has a share of 30%, its cumulative share is 30%. If the second product has a share of 20%, and the cumulative share becomes 30% + 20% = 50%. This process continues until a total of 100% share is reached.

Table 1. Extended product classification table.

	Annual demand (piece)	**Unit price (€)**	**Value (€)**	**Share in total value (%)**	**Cumulative share in total value (%)**
TPMS valve	832	40.00	33,280.00	56,14	56,14
Distance	624	20.00	12,480.00	21,05	77,19
Centering ring	2080	4.00	8,320.00	14,03	91,22
Screw M14x1.5	1040	3.00	3,120.00	5,26	96,48
Screw M12x1.25	520	4.00	2,080.00	3,51	100,00
			Σ = € 59,280.00	**Σ = 100**	

After all the necessary data for creating a Pareto diagram and a Pareto curve for the purpose of determining product classification have been determined, a Pareto diagram is made by combining of two separate diagrams into one complete diagram. The left vertical axis is the share in the total value, and the right vertical axis is the cumulative share in the total value on an observed scale of 0-100%. The horizontal axis holds the products in the exact order from the extended product classification table (Table 2). After that, a cumulative or Pareto curve is created based on the cumulative values of the analysed products [8], see Figure 4.

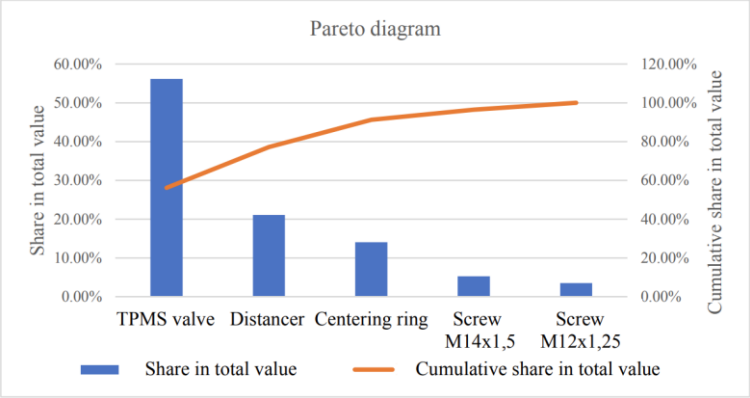

Figure 4. Pareto diagram.

5. Discussion and research results

In practice, there are several types of boundary determination between the observed groups A, B and C, and some of which are:

1. The 75/20/5 rule.
2. The 70/20/10 rule.

3. The 80/15/5 rule.
4. The 80/20 rule.

Within this research, the 80/15/5 rule was used and accordingly, in the Pareto diagram, (see Figure 5), linear boundaries are drawn from the right vertical axis to the left, from 80%, from 95% (80+15) and from 100% (80+15+5). Where the linear boundaries intersect the original Pareto curve, a vertical line is constructed in relation to the horizontal axis with products.

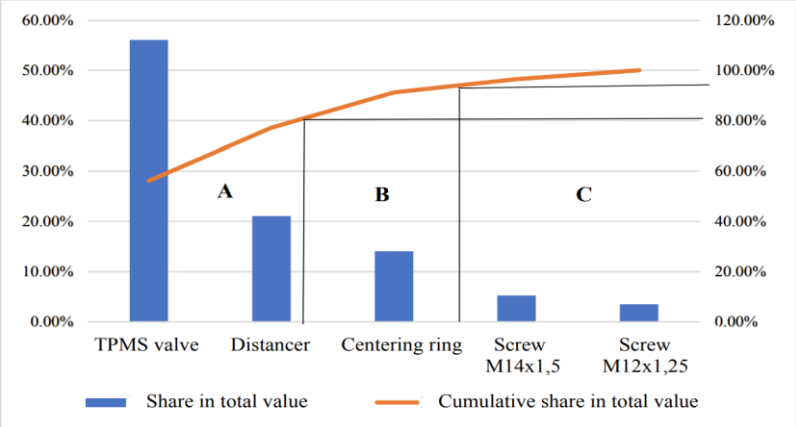

Figure 5. Determining of the ABC boundaries within a Pareto diagram.

From the above diagram, clear boundaries can be determined also which products are within which grouping. Accordingly, the products such as TPMS valves and Distance (distancer) are in the A segment and have a dominant importance in production and sales, therefore, it is in the interest of the production plant to increase the care for the mentioned products and ensure the best and fastest possible transport to the end customers. Centering rings falls in the B segment and are of medium importance, while screws belong to the C segment and can be transported as before by the standard delivery method, without additional costs and security options.

The practical application of the research results clearly shows the importance of optimizing logistics processes using Pareto (ABC) analysis, which enables the rational distribution of resources according to product priorities, which significantly improves efficiency. Products from the A category, such as TPMS valves and Distancers, require priority transport methods, including the use of express and/or personalized courier services, where the products are additionally insured during transport. More impact-resistant packaging, such as boxes with inner foam protection or vacuum packaging, is recommended, while insurance may include covering the cost of the product in the event of loss or damage. For B products, such as centering rings, standard delivery methods can be supplemented by periodic monitoring of transport conditions and better packaging, along with the basic insurance of key shipments. C products, such as screws, use cost-effective methods such as pallet transport or regular delivery without insurance, thus optimizing costs without affecting customer satisfaction. The combination of strategies for A, B and C products ensures a significant increase in the efficiency of the logistics system, while improving customer satisfaction and achieving an optimal balance between costs and service quality.

6. Conclusion

Pareto (ABC) analysis has proven to be an extremely effective tool in industrial logistics for identifying of the key elements that contribute to the success of a process. By classifying products that falls into groups, A, B and C according to their impact on total costs and values, companies are enabled to focus on the most important items that require priority attention. By introducing the Pareto principle of segmentation, processes within logistics have become more structured, enabling better inventory management, storage optimization and reduced delivery delays, although the division into only three categories is still a bit too rough when it comes to a larger analysis. ABC analysis simply focuses on one or a few criteria, although

different indicators can be combined. The technique is somewhat static in nature, lacking in dynamics and requiring the provision of consistent data.

The combination of tabular analysis and graphical presentation helps to visualize key issues and priorities, providing clear guidelines for strategic decision-making. The research results confirm the importance of proper product classification for improving transportation, faster delivery and increasing of end-customer satisfaction. Identification of priority products enabled cost reduction and efficient resource allocation.

Implementation of analytics can encounter operational challenges such as ensuring the accuracy of data, annual demand, and product value, where inaccuracies can lead to misclassification of products, impacting process efficiency. In addition, the cost-effectiveness of priority delivery requires careful assessment of costs and benefits to justify the additional investment.

The practical universality of Pareto (ABC) analysis has wide application and significant role, not only in logistics, but also in various fields, including quality control, production management and inventory planning. Its universality undoubtedly makes it an indispensable tool in modern industrial logistics practice, and by implementing these methods, companies can improve their strategic competitiveness, ensuring long-term growth and sustainable business growth.

Further research opens possibilities for studying the effects of segmentation on customer satisfaction over time, and further development of computer models, in particular, which includes factors such as delivery time and damage history, could further increase the accuracy of classification and to ensure better priority allocation in real time.

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Structural Testing of the Administrative Building

Simonović Goran[1*], Medić Senad[2] and Hrasnica Mustafa[3]

[1] University of Sarajevo, Faculty of Civil Engineering, Bosnia and Herzegovina
[2] University of Sarajevo, Faculty of Civil Engineering, Bosnia and Herzegovina
[3] University of Sarajevo, Faculty of Civil Engineering, Bosnia and Herzegovina

[*]E-mail: goransimonovic@yahoo.com

Abstract. Structural regularity of load-bearing elements should be a design goal. This does not imply that all buildings must look the same—in fact, creativity is encouraged, provided that the structural load paths are clear. However, when analyzing existing structures without original design documentation—especially those employing nonstandard load-bearing systems— it is not an easy task to determine key structural features. We found very interesting example of unusual structure. Logically we presumed simple structure with usual columns element with prevailing compression, but after we look up the whole building we discovered a truss in the roof. The main beam in the first floor hanged actually on the roof structure and the middle columns became tension elements. This explained the beam height of 600 mm, which the designer used to span 12 m.

1. Introduction

Upon completion of the renovation works, the contractor responsible for the architectural renovation of a former barracks building, company ANS Drive d.o.o. from Sarajevo, requested a structural load test from the Institute for Materials and Structures at the Faculty of Civil Engineering, University of Sarajevo,

The rehabilitation project was designed by Energoinvest d.o.o. from Sarajevo. During design, the engineer requested that the structure should be tested under trial load, having doubts about structural capacity of the original design solutions. Due to confidentiality of data, it is not allowed to present any photographs of the building or detailed information of whole project and the owner of the building, only a part of technical documentation could be shown.

2. Structural description

The building's structural system consists of cast-in-place reinforced concrete frames. The floor slabs are ribbed. The basement—which was not part of the load test—features reinforced concrete walls, columns, and braces. The ground floor includes only exterior columns and masonry infill at the facade.

The reinforced concrete beam that was tested lies above the ground floor. Its span is approximately 12 m. The beam is supported at mid-span by a tension member that transfers the load through the first and second floors and via a roof truss back down to the edge "columns." The test focused solely on verifying the beam and tension members' ability to support gravitational loads.

3. Preparations for structural testing

A contractor representative sampled reinforcement from the tension elements and measured the structure's geometry (Fig. 1).

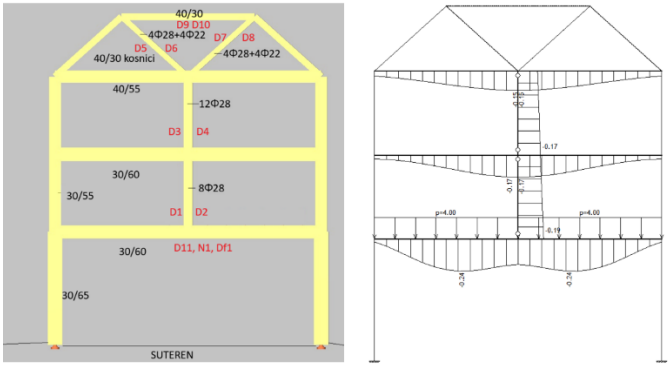

Figure 1. Geometry of the structure and measurement points, load and deflection form.

Scaffolding was installed to accommodate testing equipment. The day before the test, Institute staff installed reference markers. A total of 12 measurement points were set up to monitor strain in the reinforced concrete members, and 2 points were allocated for deflection monitoring. Strains were recorded using classical strain gauges, while deflections were measured with a levelling device and a deflectometer [2].

A detailed visual inspection took place on the same day (Fig. 2). Fine cracks were observed in the roof-level truss and in parts of the tension members. The concrete surface exhibited the typical appearance of structures built in the 1950s. All observed damages were documented photographically and in a formal record.

The trial load intensity was 3.00 KN/m^2, applied using cement bags provided by the contractor. The contractor managed the entire load application. A total of 288 cement bags (50 kg each) were placed (4 m × 12 m × 300 ÷ 50 = 288).

Two simple linear-elastic analysis models were created in the Tower software (Fig. 1). The first one modelled the reinforced concrete beams as rectangular cross-sections. The second modelled the tension elements as steel, with a cross-sectional area corresponding to the embedded reinforcement.

Figure 2. First floor and ground floors before testing.

Both models were defined with unit load (1 KN/m^2) for on-site adjustments based on actual test progress. With a frame spacing of 4 m and beam length of 12 m, the unit load per beam was 4 KN/m. Results are presented for the concrete beam model (Fig. 1). Deflections in the model with steel tie (concrete was neglected) were approximately 40 % higher.

4. Structural testing

Upon site arrival, a short meeting with all participants was held. Baseline measurements were taken at all points. Pallets with cement bags were evenly distributed on the beam (Fig. 3). In Phase 1, 12 bags were placed on each of 8 pallets, totalling 4,800 kg (1.00 KN/m^2). This was sustained for just over one hour, followed by measurements. Deflectometer Df1 recorded 0.11 mm deflection—well below the 0.19 mm theoretical value—while levelling device readings showed minimal change.

Figure 3. First phase application of 1 KN/m^2, second phase application of 2 KN/m^2.

The load was then increased to 2.00 KN/m^2 during the next hour.

After applying 2.00 KN/m^2, another round of measurements was taken. The structure was exposed to the trial loads for five hours before a final measurement reading took place. The testing results matched the results of the numerical analysis (Fig. 5). The next day, the structure was inspected, and deformation values recorded again. Slight overnight increase in the deformations was recorded. Then we add the final load increment of 1.00 KN/m^2 (totally 3.00 KN/m^2). Measurements results complied with predicted values, obtained by numerical evaluations. This was the end of the testing activities for that day.

Figure 4. The last phase application of further 1 KN/m^2, (totally 3 KN/m^2).

On the third day (Fig. 4), final measurements were taken before unloading the structure, which lasted approximately four hours. Post-unloading readings of the measurements results were taken. After unloading we recorded minimal residual deflection, which could be neglected. The test was concluded, followed by detailed results analysis and competition of the report.

5. Analysis of the testing results

Table 1 shows measurements readings obtained from classical strain gauge D11. The calculated stress for the model shown in Fig. 1. was 1.65 MPa and it almost corresponds to the value from the table 1,60MPa. Other classical strain gauges showed changes below 0.015 mm—within measurement error—and they are not shown.

Calculated deflection, presuming linear-elastic material model, at the location beneath the tension member was 3 × 0.19 = 0.57 mm.

Table 1. Measuring point D11, load, length, length differences and stress

No	Load (kN/m²)	Length (mm)	Difference (mm)	Stress (MPa)
0	0,00	3,122	0,000	0,00
1	1,00	3,140	0,018	1,03
2	2,00	3,147	0,025	1,43
3	2,00	3,148	0,026	1,48
4	3,00	3,150	0,029	1,60
5	0,00	-	-	-

The deflectometer Df1 measured a maximum of 0.61 mm. The steel-only model (neglecting concrete) predicted 0.80 mm deflection. It can be concluded that the test results are fully validated by the numerical analysis (Fig.5).

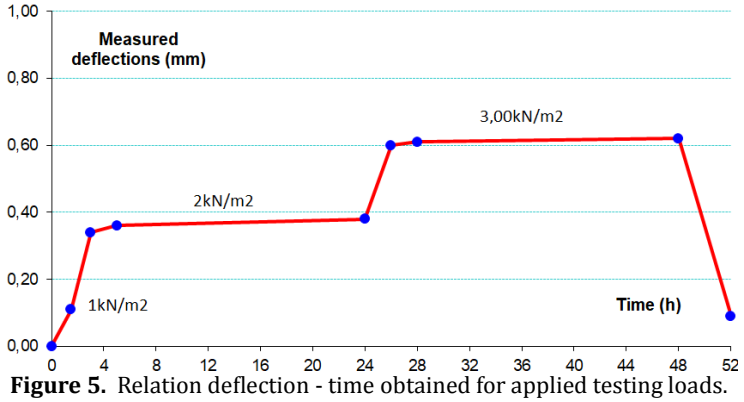

Figure 5. Relation deflection - time obtained for applied testing loads.

Geodetic measurements were only used as verification. The site engineer gave the prediction of the total deformation slightly above 0.5 mm, which corresponds quite well with the testing results obtained by deflectometer.

6. Conclusions

- The calculated deflections and stresses in the linear-elastic FEM model match the measured values.
- Small residual deflection is expected to recover over time.

- Open cracks up to 0.2 mm are normal for reinforced concrete tension members built in the 1950s and require no treatment.
- The tested structural element behaves elastically under a 3.00 kN/m^2 trial load—equivalent to service loading—demonstrating the required structural safety.

Finally, the test team was impressed that the structure, after more than 70 years in service, still responded "textbook perfectly" under load.

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Structural Testing of a Memorial

Simonović Goran*, Medić Senad and Amina Karavelić-Hadzimejlić

University of Sarajevo, Faculty of Civil Engineering, Bosnia and Herzegovina

*E-mail: goransimonovic@yahoo.com

Abstract. Usually, when we talk about structural testing using trial loading, this refers to the testing of bridges, buildings, and similar engineering structures, while monuments are rarely analysed in this way. This paper presents a load test of a monument, where the applied load intensity corresponds to the calculated design load. The aim of the test is to demonstrate that the monument possesses the required load-bearing capacity, i.e., to simulate a potential undesirable scenario such as the monument overturning.

1. Introduction

The company Grbo d.o.o. from Sarajevo, the contractor for the construction of the Memorial to the Martyrs and Fallen Soldiers of the 4th Motorized Brigade – Ilidža, requested a trial load testing of the structure from the University of Sarajevo – Faculty of Civil Engineering, specifically the Institute for Materials and Structures, upon completion of the works.

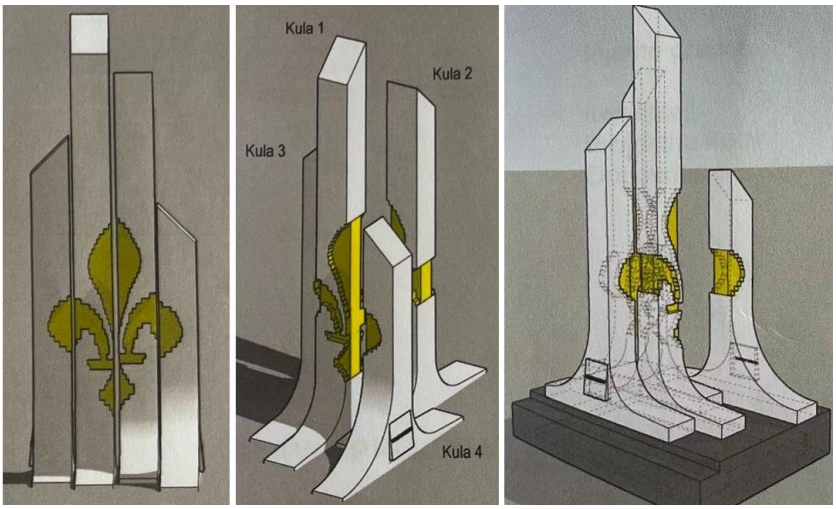

Figure 1. Excerpt from the design – 3D view of the Memorial.

The Memorial project was developed by Plan DE, a design and supervision company that also requested the structural testing [1]. The designer submitted a project excerpt and specified the guidelines for testing.

2. Structural testing

Preliminary numerical analysis indicated that expected displacements would be less than 1 mm (see below), which was decisive in selecting the measuring technique. For the experiment, highly precise LVDTs with an accuracy of one-hundredth of a millimeter were used, along with a Spider 8 signal amplifier and Catman software, all from HBK. Due to the small expected displacements, no other measuring techniques were used, except for a theodolite for control measurements.

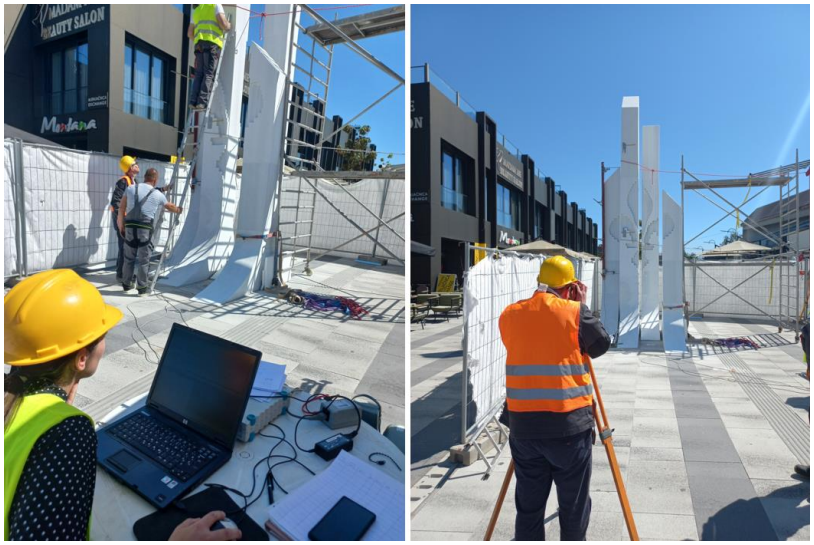

Figure 2. Experiment preparation.

Preparation for testing began on June 5, 2025, at 8:30 AM under very sunny weather conditions. The contractor's representatives set up the scaffolding and assisted with applying the trial load.

Three LVDTs were used (Fig. 3.):

- LVDT1: placed horizontally at +4.20 m
- LVDT2: horizontally at +1.55 m
- LVDT3: vertically at ground level to detect opening of the tensioned part of the structure

LVDT1 and LVDT2 were magnetically attached to a steel U-profile and further secured with adhesive tape. The steel profile was clamped to the adjacent tower using three clamps. A theodolite was also set up, and millimeter-graded adhesive measuring tapes were placed at levels +4.70 m and +2.50 m.

Figure 3. Measurement layout and applied load.

The tower at levels +4.30 m and +2.40 m was wrapped with a rope leading to a pulley on the opposite side of the platform. The rope was threaded through the pulley, and weight holders were attached to its end. The mass of the weights was marked and verified using a dynamometer.

The load was applied incrementally starting at 9:30 AM, through a total of 11 steps. Ten steel plates and a base were added at the +2.40 m level, and eight plates plus a base at +4.30 m. The base was added in the first step.

Table 1. Steps, weights, and bending moments

Step	Lower Load (kg)	Upper Load (kg)	Total load (kg)	Step Moment (kNm)	Cumulative Moment (kNm)
0	0,00	0,00	0,00	0,00	0,00
1	11,65	13,83	25,48	0,86	0,86
2	10,80	11,00	21,80	0,72	1,58
3	11,20	11,00	22,20	0,73	2,30
4	11,02	11,02	22,04	0,72	3,03
5	11,00	11,10	22,10	0,73	3,76
6	10,32	11,02	21,34	0,71	4,46
7	10,94	-	10,94	0,26	4,72
8	10,93	10,98	21,91	0,72	5,44
9	10,92	10,98	21,90	0,72	6,16
10	10,97	-	10,97	0,26	6,42
11	10,90	11,10	22,00	0,72	7,14
Total:	120,65	102,03	222,68	7,14	7,14

Load increasing data is shown in Table 1, along with the calculated bending moment for each step and the cumulative moment. At each step, steel plates were added to both ropes, except in steps 7 and 10, where weight was added only at +2.40 m.

Immediately after the load was applied, displacements were registered by the LVDTs, and values were recorded after a few minutes, once stabilized. The time between increments was a few minutes, longer in steps involving theodolite readings. After step 11, the structure remained loaded for approximately 30 minutes, followed by a 12th reading (Fig.4). Control readings with the theodolite (T1 and T2) were performed initially, as well as in steps 4 and 11. Throughout load application, theodolite readings remained below 1 mm and are not shown.

After loading, the structure was gradually unloaded. Control readings were taken after approximately 55% of the load was removed, and again after full unloading. The total unloading process lasted under 10 minutes.

Figure 3. Measurement layout and applied load.

After unloading, measurements returned almost exactly to the initial values. The slight differences were negligible, so no additional reading was taken after full stabilization.

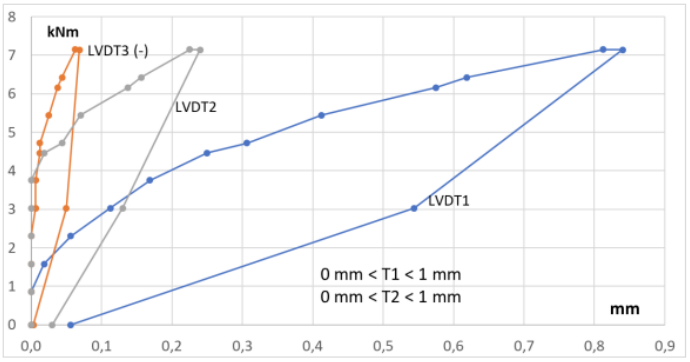

Figure 4. Bending moment – displacement relationship

It is important to note that no structural damage such as cracking was observed during the test. The test concluded at 11:15 AM.

3. Structural analysis

A relatively simple linear model was created in Tower software, assuming full fixity of the support (without considering elastic support). A modulus of elasticity of 20.4 GPa was used for the stone, and specific weight of 27 kN/m^3. The cross-section consisted of two data sets: a beam of 45x45 cm in the section without grooves, and 33x45 cm in the grooved section.

The load was applied as two concentrated forces:

- F = 1.18 kN at 2.40 m
- F = 1.00 kN at 4.30 m

Analysis showed normal tensile stresses up to 0.37 MPa. On the opposite edge, compressive stress reached -0.57 MPa, much lower than the compressive strength of the stone. The eccentricity of the compressive force was 0.36 m, outside the cross-section, so internal equilibrium could not be achieved without efficient anchors (Fig.5).

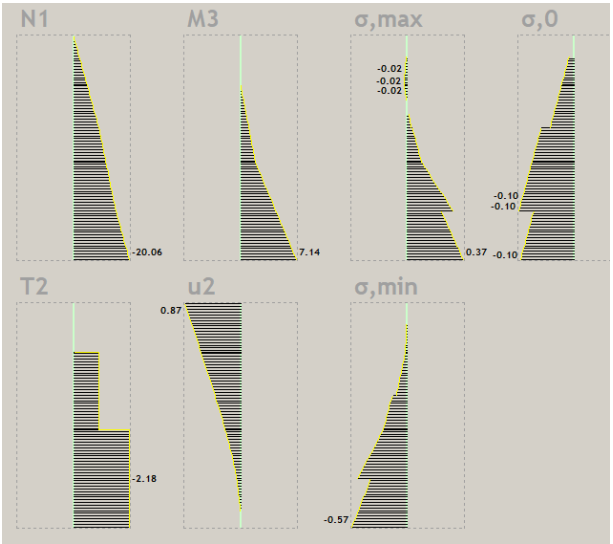

Figure 5. Calculation results.

Calculated displacements are certainly greater than those presented here, as support flexibility was not considered.

4. Conclusions

- The test achieved a bending moment of 7.14 kNm, which is 93% of the calculated (7.70 kNm) and 19% more than the required (6.00 kNm).
- At that moment, the anchors were effective and served their purpose.
- A total of 2.18 kN of horizontal load was applied.
- Theodolite-measured displacements at the top were under 1 mm. Calculated horizontal displacement at the top was 0.87 mm. Measured LVDT values matched the calculations.
- No cracks or damage to the structure were recorded.
- Upon unloading, the structure returned to its original state.
- The structure behaved elastically and is considered capable of carrying the designed loads.

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SECTION/SEKCIJA
B

Assessment of wood properties in standing trees: acoustic tomograph vs. fractometer

Nebojša Todorović[1*], Ivana Živanović[2] and Goran Milić[1]

[1] Wood Science and Technology, University of Belgrade-Faculty of Forestry, Belgrade, Serbia
[2] Institute of Forestry, Belgrade, Serbia

[*]E-mail: nebojsa.todorovic@sfb.bg.ac.rs

Abstract. This study aimed to assess the wood properties of red oak (*Quercus rubra* L.) trees from three locations in Serbia and to evaluate the effectiveness of acoustic tomography (a non-destructive method) and the fractometer (a semi-destructive method) in analyzing anatomical, physical, and mechanical properties of standing trees. The Arbotom 2D pulse tomograph (Rinntech) evaluates wood quality based on the propagation of sound waves, while the Fractometer (Rinntech) measures parameters such as bending strength, fracture angle, and compressive strength parallel to the fibers using core samples, providing valuable insights into wood characteristics. Measurements for both tomography and fractometer assessments were taken at the midpoint of the stems of nine trees. The results showed that tangential sound velocity (average: 1533 m/s) was a better predictor of wood properties than radial sound velocity (average: 1551 m/s). The fractometer parameters were as follows: average bending strength of 9.3 MPa, the fracture angle of 17.2°, and compressive strength parallel to the fibers of 35.5 MPa. While bending strength showed a weak correlation with mechanical properties, the fracture angle and compressive strength parallel to the fibers emerged as more reliable indicators of wood quality. It was observed that the fractometer-based models provided more reliable assessments of mechanical properties than those derived from acoustic measurements. Acoustic tomography offers a fast and non-destructive overview of internal wood structure, whereas the fractometer provides detailed insights into mechanical properties. Together, these methods complement each other, enabling a comprehensive assessment of wood quality in standing red oak trees.

1.Introduction

The determination of internal wood quality in live trees is central to contemporary forestry and arboriculture, particularly where tree vitality is a concern. Various nondestructive testing (NDT) techniques, including acoustic measurements, have attracted much attention due to their effectiveness and reliability. Acoustic tomography allows internal defects including decay, voids or low density areas to be visualized by determination of the speed of stress wave propagation through wood tissues (Bucur, 2006, Gilbert & Smiley, 2004). Its use has been particularly effective in urban forestry and risk estimation, because it is not invasive and data are quickly collected (Nicolotti et al., 2003; Hiziroglu, 2016).

An acoustic alternative to the Fractometer, which offers semi-destructive measures of mechanical properties by measuring bending strength and compression in increment cores (Rinn et al., 1996; Tang et al., 2005), has yet to be developed. The Fractometer has been used extensively for assessing standing trees because, even with very little core sampling, it can assess relative resistance to bending, compressive strength parallel to grain, and fracture angle—parameters that are highly determinative of the quality of residual wood (Chiu et al., 2006; Matsumoto, 2010).

Several studies have been undertaken in recent years to develop models to predict wood properties, namely density, modulus of rupture (MOR), modulus of elasticity (MOE) from acoustic velocity and fractometric data (Gerhards, 1982; Auty &Achim, 2014; Doung & Hasegawa, 2024). These models are usually based on multivariate regression or chemometric techniques and their performance is measured using statistical measures such as R^2 (coeficient of determination), RPD (residual predictive deviation) and RPIQ (residual predictive interquartile quality) (Schimleck et al., 2001; Bellon-Maurel et al., 2010).

Acoustic-based models are generally more appropriate for fast and large-scale screening models, whereas fractometer models often provide higher precision, especially for the mechanical traits (Sandak et al., 2016; Nowak et al., 2021).

The acoustic methods are convenient to implement on a large scale and give quick results. Fractometry in contrast, is better suited for detailed assessments as needed for quality grading and forest planning. Combining these two approaches results in a comprehensive evaluation of wood quality. These results are in accordance with previous studies in analogous cases of non-destructive wood testing and indicate that larger numbers of input data, as well as further exploring the predictive performance of both tools with more advance modelling techniques, will be necessary to enhance the prediction capabilities of both devices. In this study, 164 core samples from nine red oak trees were collected and analysed using both acoustic tomography and fractometry in order to develop and compare predictive models for assessing internal wood quality.

The primary objective was to evaluate the effectiveness of these complementary methods in estimating anatomical, physical, and mechanical properties of standing trees, and to determine their potential application in forestry diagnostics and resource management.

2.Materials and methods

The study was conducted on red oak (*Quercus rubra* L.) trees from three different forest locations in Serbia: Bruske šume, Stepin lug, and Debeli lug. The purpose was to assess internal wood quality using two complementary non-destructive and semi-destructive methods: acoustic tomography and fractometry.

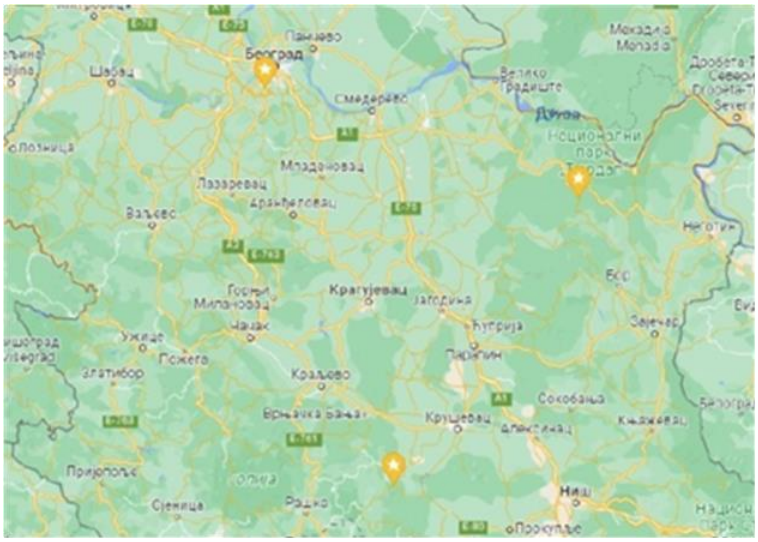

Figure 1. Locations of sampled trees in Serbia

Locations of sampled trees are shown on the map (Figure 1), illustrating geographic distribution relevant to different environmental conditions that may influence wood properties.

Acoustic tomography was applied using the Rinntel Arbotom Sonic Tomograph. The system measures sound velocity propagation in the cross-section of standing trees, where lower velocities indicate potential decay, voids, or less dense tissues, and higher velocities indicate intact, sound wood. The tomograph was applied at breast height (1.3 m), with 6 to 10 sensors placed around the tree circumference. Each signal was transmitted and received between each sensor pair, producing a tomogram with colored zones representing speed ranges (Figure 2). The fractometer (IML Fractometer II) was used to analyze core samples taken with an increment borer at two heights on each tree (1.3 m and 3.5 m) from four cardinal directions. It measured compressive strength parallel to fibers, bending strength, and fracture angle (Figure 3).

Figure 2. Arbotom *(Orig.)*

Figure 3. Fractometer 2 *(Orig.)*

Two cross-sectional tomograms and eight increment cores were obtained from each tree. One hundred sixty-four core samples were tested. For macroscopic and microscopic characterization of red oak wood, cross-sectional discs were cut and processed with a CNC machine, sanded and polished in order to expose the growth rings. The thickness of earlywood and latewood were measured microscopically in the microscope stage, samples were calibrated with the milimeter paper and were observed until 200×. Wood fiber anatomical assessments were carried out at the Faculty of Forestry in Ljubljana; samples were chemically and mechanically treated to macerate fibers and analyzed under a BioBlue microscope with automatic fiber counting software. A total of 600 samples (20×20×320 mm) were conditioned under controlled environmental conditions and tested for physical and mechanical properties. The density and moisture content and the bending strength and compressive strength parallel to the grain were measured with a wood universal testing machine (VT4VT). Pearson correlation, descriptive statistics and stepwise regression were used for the statistical analysis of the measured values of sound speed in the radial direction, angle of fracture and compressive strength. Variables were multivariate modeled after verifying their normality and collinearity. Performance of the predictive models was judged by residual predictive deviation (RPD); values higher than 5 denote high model accuracy (Schimleck et al. 2001; Sandak et al. 2016b). Statistical analysis All analyses were conducted using the Statgraphics ver. XVI. I (StatPoint Technologies, VA, USA).

3.Results and disccusion

Standing red oak (Quercus rubra L.) timber quality was assessed with acoustic annli tomography to gain critical knowledge of the internal structure and mechanical integrity of the wood. Sound transverse wave velocity ranging from 1505 m/s to 1595 m/s at the tested sites (Bruske šume, Debeli lug, and Stepin lug), was a measure of the density characteristics, as well as inner defects of wood. Tangential velocities were relatively low, in agreement to wood's anisotropy.

Mechanical parameters, such as compressive strength and fracture angle, were determined by fractometrical data. Results of compressive strength—35.61 MPa in Bruske šume, 37.83 MPa in Debeli lug and 33.02 MPa in Stepin lug indicated structural uniformityThere was no observed correlation between the fractometric and standard tests for bending strength in this study, which contrasts with the findings of Gruber and Hagerman (2000), who reported a significant relationship. Hans and Allison (2021) found that compressive strength was closely related to axial bending in red oak. Similarly, Lin *et al*. (2003) reported an increase in bending strength from the pith toward the bark in Taiwania cryptomerioides. Mastumoto *et al*. (2010) and Bari *et al*. (2001) also found a strong correlation between fractometric compressive strength and wood density.

Statistical modeling validated compressive strength and crack angle as consistent predictors with determination coefficients up to (R^2 = 0.9778). Tang et al. (2016) also reported compression and bending strength as the strongest fractometric indicators of wood quality.

Table 1 – Multiple regression models and adjusted determination coefficients for wood properties tested by standard destructive method and fractometer.

Wood Property	Regression Model	Correlation Coeff. (r)	Standard Error
Density (WD)	yWD = 0.01549·σpF + 0.00777·BaF	0.9778	0.11
Compressive strength (Hp)	yHp = 1.171·σpF + 0.954·BaF	0.9704	10.36
Bending strength (MOR)	yMOR = 2.728·σpF + 1.160·BaF	0.9621	23.74

The average MOR had a broader range, 8.51 to 9.998 MPa. The weak correlation between this parameter and the acoustic velocity confirmed that bending strength is less reliable predicted by sonic method. On the other hand, all folds combined, the fracture angles exhibited similar general patterns over the sites and moderate to strong correlation with the acoustics. A statistical model using acoustic data was developed based on comparisions in order to predict properties such wood density, compressive strength, modulus of rupture (MOR), modulus of elasticity (MOE), fibre length and latewood proportion. Models performance was evaluated by multiple regression and residual prediction deviation (RPD) statistics.

Extensive research has been conducted on the relationship between elastic wave velocity and the properties of wood. This study demonstrated that velocity of sound is highly related to important mechanical characteristics of red oak wood. Acoustic velocity correlated well with wood density (r=0.594–0.825) and MOE (r = 0.603–0.835), but only moderately with compressive strength (r=0.510–0.606), and weakly with fiber length and latewood percentage. Grouped regression models of velocities exhibited predictive potential particularly for density and MOE but with weak performances for MOR. These results are consistent with studies of Doung and Hasegawa (2024) and Auty and Achim (2014), through which the acoustic confirming that acoustic wave speed can serve as a useful non-destructive predictor of red oak wood quality.

Table 2. Regression models of mechanical wood properties based on acoustic velocity

Wood Property	Regression Model	Correlation Coeff. (r)	Standard Error
Density (WD)	y = 0.649335 + 0.0000246251*Vsr	0.705	0.015
Modulus of Elasticity(MOE)	y = 7714.66 + 1.13413*Vsr	0.603	933.1
Latewood Percentage (Pkz)	y = 51.7135 + 0.00471298*Vsr	0.385	7.015

Acoustic velocity is moderately correlated with wood density (r = 0.705) and weakly linked to MOE (r = 0.603) and latewood percentage (r = 0.385), according to regression analysis. SV nicely predicts density, but has limited predictive power for elastic and anatomical properties. Consequently, acoustic models are better for predicting physical properties of wood, rather than its anatomical features. Relative percent deviation (RPD) of the two methods are presented in Table 3 as Comparative Model Reliability Indices. Fractometer models proved to have higher RPD values for MOR (4.64) and compressive strength (3.09) and can be classified in the screening and high reliability quality of prediction ranges. Although acoustic tomography models showed higher Rp^2 values (e.g., Rp^2 = 0.898 for MOR), their RPD values were lower, indicating reduced predictive power.

Table 3 - Comparative Model Reliability Indicators (Fractometer vs. Acoustic Tomograph)

Wood Property	Method	Sample Size	SEP	Rp^2	RPD
Wood Density (WD)	Fractometer	39	0.052	0.5531	1.53
Wood Density (WD)	Acoustic Tomograph	24	0.0085	0.666	1.57
Compressive Strength (Cs)	Fractometer	36	2.112	0.353	3.09
Compressive Strength (Hp)	Acoustic Tomograph	28	0.557	0.738	1.56
Modulus of Rupture (MOR)	Fractometer	46	3.828	0.378	4.64
Modulus of Rupture (MOR)	Acoustic Tomograph	23	2.950	0.898	1.51
Modulus of Elasticity (MOE)	Fractometer	49	1284.266	0.663	1.20
Modulus of Elasticity (MOE)	Acoustic Tomograph	24	325.282	0.632	1.61

In the case of MOE, both approaches had moderately low RPD values, pointing towards a low predictability and the need for model improvement. Generally, prediction using models based on the fractometer will be extended in more detail with higher predictive certainty under several input variables than acoustic models, which, while faster, relied on a single parameter (sound velocity) and were less precise.

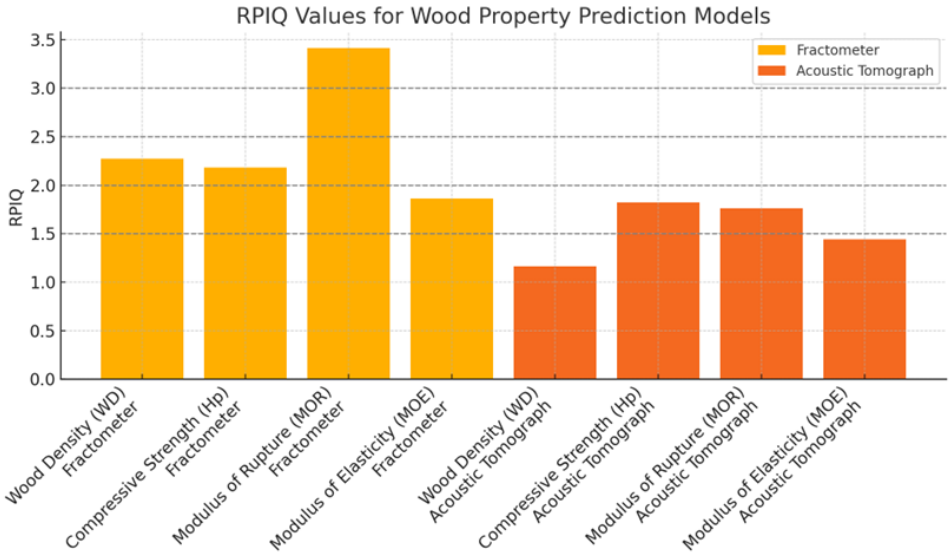

Figure 2. RPD values for fractometer and acoustic tomograph models

The graph compares the RPD (relative percent difference) values obtained for four wood properties (wood density (WD), compressive strength (CS), MOR and MOE), when fitted with fractometer and acoustic tomography models. The RPD of both types of model are also reported in Table 3. While the acoustic

tomography models generally fall within the "screening" category (RPD < 5.0) according to the ForestCom quality benchmark, the fractometer models consistently exceed this threshold. In fact, all fractometer-based models achieved RPD values above 5.0, indicating high predictive accuracy and suitability for more advanced applications beyond basic screening.

RPIQ values are presented in Table 4 for both methods. The predictive precision of the fractometer models, specifically for MOR (RPIQ=3.41), is excellent. In contrast, the acoustic tomography models exhibited moderate RPIQ values, supporting their role primarily as tools for rapid, preliminary assessments. These results confirm that while the acoustic tomograph is effective for fast, non-destructive screening, the fractometer offers superior accuracy in predicting mechanical properties and is more suitable for detailed wood quality evaluations.

Table 4 - Comparative Model Reliability (RPIQ) Indicators (Fractometer vs. Acoustic Tomograph)

Wood Property	Method	Sample Size	IQR	RMSE	RPIQ
Wood Density (WD)	Fractometer	39	0.05	0.12	2.27
Wood Density (WD)	Acoustic Tomograph	24	0.01	0.01	1.16
Compressive Strength (Cs)	Fractometer	36	3.92	8.52	2.18
Compressive Strength (Hp)	Acoustic Tomograph	28	0.55	1.0	1.82
Modulus of Rupture (MOR)	Fractometer	46	7.82	26.68	3.41
Modulus of Rupture (MOR)	Acoustic Tomograph	23	2.89	5.07	1.76
Modulus of Elasticity (MOE)	Fractometer	49	1421.49	2639.28	1.86
Modulus of Elasticity (MOE)	Acoustic Tomograph	24	318.43	457.0	1.44

To evaluate the predictive capability of the models developed using two measurement approaches—Fractometer and Acoustic Tomograph—RPIQ (Residual Predictive Interquartile Range) values were calculated for each. The models were constructed to estimate various wood characteristics, and their performance was assessed based on the degree of agreement between predicted and observed values using RPIQ as a key indicator of model reliability.

Figure 3 presents a bar chart comparison of the RPIQ values obtained for each analyzed property using both approaches. The MOR (modulus of rupture) estimated with the Fractometer provided the best RPIQ value (3.41), indicating excellent agreement between predicted and measured values. In contrast, the MOE model based on acoustic method had a low RPIQ (1.44), indicating only moderate predictability.

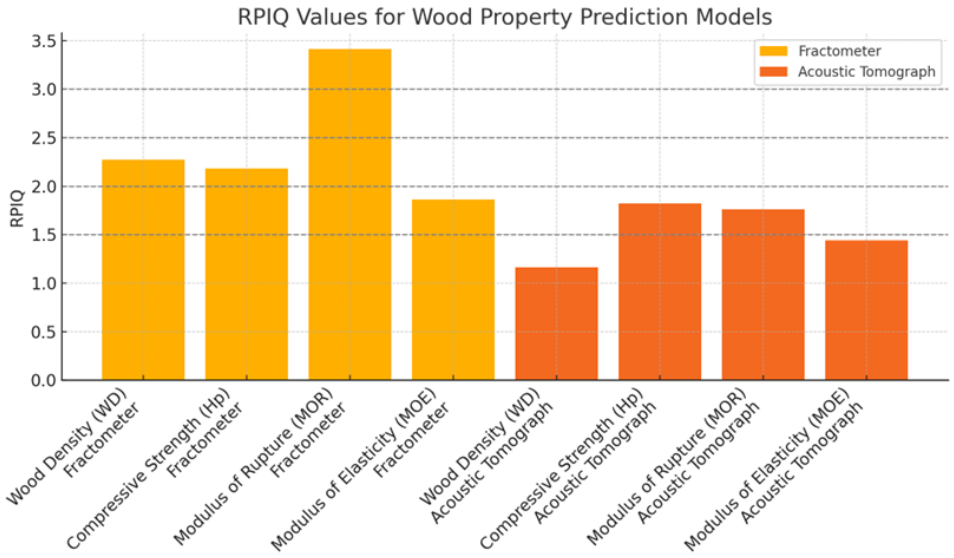

Figure 3. RPIQ values for fractometer and acoustic tomograph models

Fractometer models outperformed acoustic tomography in predicting main mechanical properties. Specifically, they achieved excellent RPIQ values for modulus of rupture (3.41) and compressive strength (2.18). Predictions for wood density (2.27) and modulus of elasticity (1.86) also yielded adequate RPIQ scores, making these models suitable for initial screening purposes. In comparison, Acoustic Tomograph models had lower RPIQ values in the case of mechanical properties (e.g., 1.16 for WD and 1.44 for MOE) indicating limited reliability for accurate predictions. However, they demonstrated good potential in predicting anatomical characteristics : for instance 2.73 for fiber length and 2.34 for latewood percentage. Although Fractometer provides a more accurate model on the basis on the multivariate mechanical measurements, the Acoustic Tomograph still works to achieve a quick inner diagnostics. These findings are consistent with previous studies (Matsumoto et al., 2010; Sandak et al., 2016), which underscored the importance of using both techniques in the full non-destructive wood evaluation.

4.Conclusions

This research showed potential of two noninvasive methods – fractometer and acoustic tomograph – for assessing mechanical properties of standing red oak trees. Although both approaches producing useful information, fractometer models were found to be more reliable and accurate for mechanical properties such as CS and MOR. High RPIQ scores (3.41 for MOR, 2.18 for Hp) confirmed their strong predictive performance. In contrast, acoustic tomograph models showed moderate RPIQ values (1.76 and 1.44 for MOR and MOE, respectively), demonstrating limited realibility in predicting mechanical properties. The estimation of modulus of elasticity based solely on sound velocity is severely limited, due to the use of a single predictive parameter.

The attenuation tomograph, however, remains useful in diagnosis of internal defects such as decay and hollow. The data analysis conducted demonstrated the greater statistical strength and closeness with destructing test results of the multivariate input in the Fractometric models. These results could support the application of fractometric analysis in different species and its use in forestry.diagnostics. This study contributes to the limited regional knowledge on red oak wood quality and enhances more informed resource management. The abilities of the models to predict defectived FAs were confirmed by respective RPD and RPIQ values.

Due to their efficiency and portability, acoustic techniques are well suited for rapid, large-scale assessments. In contrast, fractometric analysis is more appropriate for detailed evaluations required in

quality grading and forest planning. Integration of the two approaches provides a holistic and balanced approach to wood quality evaluation. These results align with previous studies in non-destructive wood testing and suggest that future research should include additional variables and more advanced modeling techniques to enhance the predictive capabilities of both tools.

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Impact of operating temperature on the heat balance and efficiency of pits when steaming unfrozen logs

Nencho Deliiski[1*], Dimitar Angelski[2], Pavlin Vitchev[1] and Krasimira Atanasova[2]

[1] Department of Woodworking Machines, University of Forestry, Sofia, Bulgaria
[2] Department of Furniture Production, University of Forestry, Sofia, Bulgaria

[*]E-mail: deliiski@netbg.com

Abstract. An approach for computing the heat balance and heat efficiency of concrete pits when steaming unfrozen logs intended for production of peeled veneer has been presented. With the help of our personal non-stationary model, the heating times of beech logs with a diameter of 0.4 m, initial temperature of 10 °C, and moisture content of 0.4, 0.6, and 0.8 kg·kg^{-1} were determined at operating temperature of the steaming medium in the pit equal to 70, 80 and 90 °C. Using the determined logs' heating times and our own stationary model of the heat balance of concrete pits when steaming logs, the change in the total energy required to carry out the entire steaming process and that required for each of the individual components of the heat balance were calculated. Computations were conducted for a concrete pit with overall dimensions 7.4 × 2.8 x 2.5 m, working volume of 20 m^3, and a degree of filling with logs 45, 60, and 75%, It was found that the increase in the operating temperature from 70 to 90 °C at maximum possible loading level of 75% causes an increase in the energy consumption of the pit from 103.4 to 127.0 kWh·m^{-3} and a decrease in the heat efficiency of the pit from 39.1 to 38.9%.

1. Introduction

It is well known, that the steaming of the logs in pits is mostly carried out for the purpose of their plasticizing, in order to reduce the cutting resistance during the formation of quality veneer [1, 2, 6, 10, 14-20]. Such steaming is characterized by high energy consumption and low heat efficiency. References [11, 16] note that the efficiency of the heat treatment of logs with saturated water steam in pits in veneer production does not typically exceed 18%. In [8] is stated that the loading level of the pits, that is, the degree of filling with logs cannot exceed 75% of their working space.

Publications devoted to the energy required to steam or boil logs in pits are very scarce. Only in [7] a model of heat balance of concrete pits was proposed and it was used to calculate such a balance of the pit shown in Fig. 1 during the boiling of unfrozen beech logs in it.

The aim of the present work is to supplement the model given in [7] for the case of steaming logs in concrete pits and to use it to study the influence of the operating temperature on the heat balance and heat efficiency of the same pit during steaming of unfrozen veneer logs in it.

2. Material and methods

2.1 *Design features of the pit, in which the logs are subjected to steaming*

This study was carried out on the heat balance and efficiency of the shown in Fig. 1 pit having the following overall dimensions: length L_p = 7.4 m, width B_p = 2.8 m, and depth H_p = 2.5 m. Part of the pit is located above ground level, and the rest is below it.

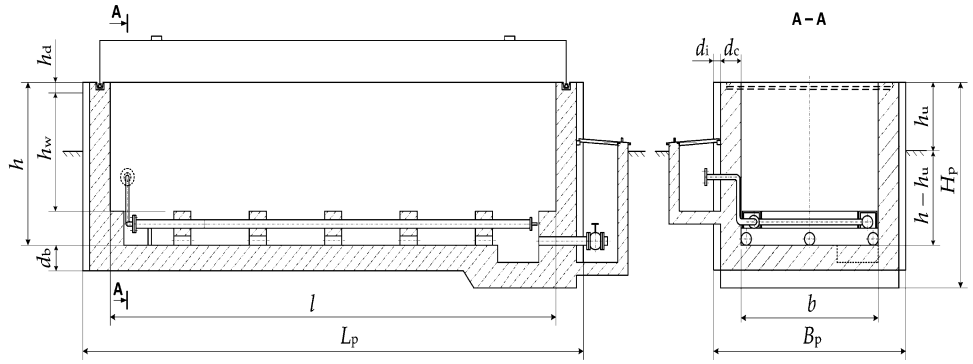

Figure 1. Longitudinal and transverse sections of the pit for steaming wood materials used during the computations of its heat balance and efficiency

The symbols, units, and values of all the others marked in Fig. 1 pit parameters of the pit are given in the upper half of Table 1.

The pit is a concrete tank with steel reinforced walls and bottom, which are well thermally and hydrofobically insulated.

During the steaming of wood materials, the pit is closed with a removable well thermally insulated metal lid in order to protect the service workers from falling into the working area of the pit, as well as to eliminate heat losses into the surrounding air. The walls of the pit's construction are finished with a groove filled with water, into which the protruding edge of the lid is immersed when the pit is closed, creating a perfect water seal.

The required operating temperature in the pit during steaming of logs in it is provided by direct water steam, which is introduced into the pit using heating elements of a tubular radiator. The radiator is located in the lower part of the pit and is supplied with water steam from a steam generator of appropriate performance.

The tubular elements of the radiator are perforated on their underside and the steam passes through a layer of condensed water when heating the pit and the logs in it. After the steaming is completed, the pit's lid is moved, the plasticized logs are directed to the veneer machines, and the condensed water is drained from the pit.

2.2. Logs and their steaming regimes parameters used in the computations

The present study was carried out with non-frozen beech (*Fagus sylvatica* L.) logs, the steaming of which in a pit was simulated using regimes commonly applied in practice.

These steaming regimes consist of two stages, during which the operating temperature t_m changes as follows (Fig. 2):

▪ During the first stage, in the course of time 0 – τ_1, an increase in t_m from t_{m0} to t_{m1} takes place by fully or partially opening the valve to introduce saturated water steam to the pit;

▪ During the second stage of the regimes, in the course of time τ_1 – τ_2, dosed introduction of the steam into the pit's radiator is carried out in order to maintain a constant technologically permissible value of t_m, equal to the maximum regime's value t_{m1}. When the time τ_2 is reached, the logs subjected to steaming reach the optimal temperature required for their subsequent mechanical processing and the regime ends.

The symbols, units, and values of the logs' and also of the steaming regimes' parameters involved in the equations of the models solved below, which were used in the numerical calculations of the pit's heat balance and efficiency, are presented in in the lower half of Table 1.

2.3. Modelling of the 1D temperature distribution in non-frozen logs subjected to steaming

Since the heating of non-frozen logs is a multifactorial process, the duration τ_2 of the steaming regimes is most suitable to be determined with the help of a non-stationary mathematical model
adequate to the real process. When the length of the logs, L, is at least 4 times their diameter, D, their required heating duration can be determined using the following experimentally verified 1D model [4, 5]:

$$c_{\text{w-unfr}} \cdot \rho_{\text{w}} \frac{\partial T(r,\tau)}{\partial \tau} = \text{div}(\lambda_{\text{wr-unfr}} \text{ grad } T) \quad (1)$$

at

$$T(r,0) = T_{w0} \tag{2}$$

and boundary conditions for conductive heat transfer:

$$T(0,\tau) = T_m(\tau) \tag{3}$$

where $c_{w\text{-}unfr}$ is the specific heat capacity of the non-frozen wood, J·kg^{-1}·K^{-1}; $\lambda_{wr\text{-}unfr}$ – thermal conductivity of the non-frozen wood in redial direction, W·m^{-1}·K^{-1}; ρ_w – density of the wood, kg·m^{-3}; r – coordinate along the log's radius: $0 \le r \le D/2$, m; D – diameter of the log, m; T – temperature, K; T_{w0} – initial temperature of the wood, K; T_m – operating medium temperature of the steaming medium in the pit, K; τ – time, s.

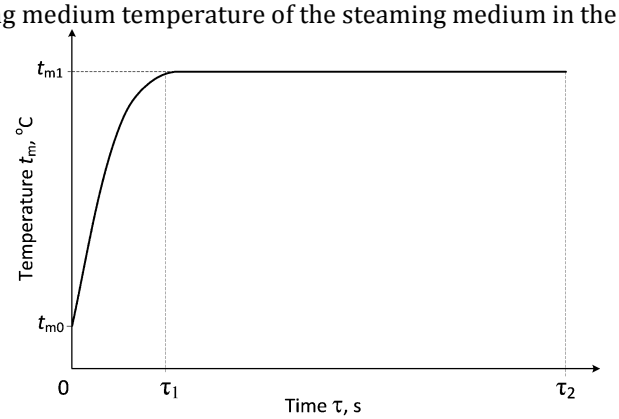

Figure 2. Change of the operating temperature t_m in regimes for steaming of wood materials in pits

Equation (3) mathematically describes the fact that due to the very high heat transfer of the condensing water steam to the surface of the logs, its temperature is practically the same as the operating temperature of the steaming medium in the pit.

Mathematical descriptions of all thermo-physical characteristics of unfrozen wood, which are involved in the model (1) – (3), have been made and verified with foreign experimentally obtained dissertation data in [2, 9, 10, 13, 14] as a function of the temperature and wood moisture content. The mathematical description of the operating medium temperature, t_m, is analogous to that proposed in [3, 6] for t_m in autoclaves for steaming wood materials.

2.4. Mathematical model of the heat balance and efficiency of pits when steaming logs

The heat balance of the pits when steaming logs in them can be mathematically presented by the following model in a general form:

$$Q_{\text{Pit-steaming}} = Q_{\text{Wood}} + Q_{\text{Constr.}} + Q_{\text{Cond. water}} + Q_{\text{Radiator}} + Q_{\text{Heat losses}} \tag{4}$$

where $Q_{\text{Pit-steaming}}$ is the total specific (relating to 1 m^3 wood) heat energy, required for the implementation of the entire processes of plasticizing the logs subjected to steaming in the pit; Q_{Wood} – energy required for warming up of the logs themselves subjected to steaming; $Q_{\text{Constr.}}$ – energy required for heating of the pit's construction materials; $Q_{\text{Cond. water}}$ – energy contained in the condensed water that is removed from the pit at the end of the steaming regimes; Q_{Radiator} –

energy required to heat the metal radiator of the pit, with the help of which saturated water vapor is introduced when steaming logs; $Q_{\text{Heat losses}}$ – energy required to cover heat losses of the pit during the entire logs' steaming process. The unit of all specific energies Q in equations (4) and (5), and also everywhere below, is kWh·m^{-3}.

Table 1. Basic set parameters used to solve the mathematical models of the pit's heat balance

№	Parameter name	Symbol	Unit	Value
	Parameters of the steaming pit			
1.	Length of the working volume of the pit	l	m	6.6
2.	Width of the working volume of the pit	b	m	2.0
3.	Depth of the working volume of the pit	h_w	m	1.52
4.	Depth of the upper (above-ground) part of the pit	h_u	m	0.8
5.	Thickness of the walls and bottom of the pit	d_c, d_b	m	0.3
6.	Thickness of the insulating layers of walls and lid	d_i, $d_{i\text{-lid}}$	m	0.1
7.	Thickness of the steel sheets of the pit's lid	d_{Fe}	m	0.004
8.	Density of the concrete walls and bottom of the pit	ρ_c	kg·m^{-3}	2300
9.	Density of the insulating layers of the walls and lid	ρ_i, $\rho_{icov.}$	kg·m^{-3}	350
10.	Density of the steel sheets of the lid	ρ_{Fe}	kg·m^{-3}	7850
11.	Initial temperatures of the pit's walls and bottom	t_{cu0}, t_{bg0}	°C	10
12.	Initial temperatures of the insul. layers and soil	t_{iu0}, t_{ig0}, t_{s0}	°C	10
13.	Specific heat capacity of the concrete	c_c	J·kg^{-1}·K^{-1}	1134
14.	Specific heat capac.of the ins.layers of walls and lid	c_i, $c_{i\text{-lid}}$	J·kg^{-1}·K^{-1}	850
15.	Specific heat capacity of the steel sheets of the lid	c_{Fe}	J·kg^{-1}·K^{-1}	444
16.	Thermal conductivity coefficient of the concrete	λ_c	W·m^{-1}·K^{-1}	1.28
17.	Thermal conductivity coefficient of the ins. layers	λ_i	W·m^{-1}·K^{-1}	0.042
18.	Specific mass of the heating elements of the radiator on 1m^2 of the area at the bottom of the pit	m_{he}	kg·m^{-2}	100
19.	Distance of the drainage channel from the upper edge of pit	h_d	m	0.13
	Technological parameters of the steaming process of beech logs with a diameter of 0.4 m			
1.	Loading level of the pit with logs	f	%	45,60,75
2.	Moisture content of the logs	u	kg·kg^{-1}	0.6
3.	Fiber saturation point of the beech wood	u_{fsp}	kg·kg^{-1}	0.31
4.	Basic density of the beech wood	ρ_b	kg·m^{-3}	560
5.	Density of the water in the pit	ρ_{H2O}	kg·m^{-3}	998
6.	Initial average mass temperature of the logs	t_{w0}	°C	10
7.	Average temperature of the logs at the end of their steaming (* – at t_{m1} = 70 °C; ** – at t_{m1} = 80 °C, and *** – at t_{m1} = 90 °C)	$t_{avg\text{-}end}$	°C	66.8* 72.7** 78.6***
8.	Initial value of the operating temperature in the pit	t_{m0}	°C	10
9.	Maximum value of the operating temperature in the pit during steaming of logs	t_{m1}	°C	70*,80**, 90***
10.	Temperature of the steam that feeds the radiator	t_{steam}	°C	130
11.	Temperature of the surrounding air near the pit	t_{air}	°C	10
12.	Duration of increase in t_m from t_{m0} to t_{m1}	τ_1	h	4.0
13.	Duration of the steaming process of logs, depending on wood moisture content u and t_{m1}	$\tau_2 = \tau_{boil}$	h	27.0* 20.0** 16.5***
14.	Condensation heat of steam in the pit at $\tau = \tau_2$ and t_{m1} = 80 °C	r_{steam}	MJ·kg^{-1}	2308
15.	Enthalpy of the condensation water in the pit at t_{m1} = 80 °C	h_{cw}	MJ·kg^{-1}	335

Mathematical descriptions of the individual components of the heat balance, which participate in the right-hand sides of equation (4) are given in [7]. In this reference only a mathematical description of the component $Q_{\text{Cond. water}}$ in equation (4) is missing. This component can be calculated using the following equations:

$$Q_{\text{Cond.water}} = m_{\text{cw}} \cdot \frac{h_{\text{cw}}^{\tau_2}}{3.6 \cdot 10^6 \cdot V_{\text{w}}} \tag{5}$$

where

$$m_{\text{cw}} = 3.6 \cdot 10^6 \cdot V_{\text{w}} \cdot \frac{Q_{\text{Wood}} + Q_{\text{Constr.}} + Q_{\text{Heat losses}}}{r_{\text{steam}}^{\tau_2}} \tag{6}$$

The volume of the wood materials subjected to steaming in the pit, V_w, which participates in equations (5) and (6), is equal to

$$V_{\text{w}} = f \cdot V_{\text{pit}} \tag{7}$$

where f is the loading level of the pit with wood materials subjected to steaming, m^3·m^{-3}; V_{pit} – working space of the pit equal to (refer to Fig. 1)

$$V_{\text{pit}} = l \cdot b \cdot h_{\text{w}} \tag{8}$$

The values of the mass of condensed water in the autoclave, m_{cw}, and the energy dependent on it, $Q_{Cond.\ water}$, are calculated for the conditions of the end of the second stage of the steaming regimes, i.e. at $t_m = t_{m1}$ and $\tau = \tau_2$, when the valve for draining the condensed water from the pit is fully opened. The mass m_{cw} is formed by the amount represented in $J \cdot m^{-3}$ of the sum of the energies Q_{Wood}, Q_{Constr}, and $Q_{Heat\ losses}$ after dividing it by condensation heat of steam in the pit, r_{steam}, at the moment $\tau = \tau_2$. The values of enthalpy of the condensation water, h_{cw}, and of r_{steam}, are given in Table 2. They are taken from reference books with thermodynamic parameters of water and saturated steam at $t_{m1} = 80$ °C [6].

The heat efficiency of the tested concrete pit when steaming logs with different wood moisture content u in it under conditions of different filling levels f of the pit with logs is calculated (in %) according to the following equation:

$$\eta_{\text{pit-steaming}} = 100 \frac{Q_{\text{Wood}}}{Q_{\text{steam-total}}} \tag{9}$$

2.5. Solving models (1) – (3) and (4) – (9)

The mathematical descriptions of t_m and the thermophysical characteristics of wood were entered into the model (1) – (3) and it was solved with the help of the finite difference method using own software program in the Visual FORTRAN Professional. From the obtained change of the temperature field along the radius of the logs, and in particular from that of the temperature in their center and of the average mass temperature t_{avg}, the duration of the steaming process of the logs, τ_2, indicated in Table 1, was determined for the three investigated maximum values of the operating temperature in the pit, namely $t_{m1} = 70$, 80, and 90 °C. The value of t_{avg} (in K) at the end of the steaming regimes is needed to calculate the energy Q_{Wood} in equation (4).

An Excel program has been prepared for joint solving of the equations involved in the models (4) – (9). Using this program, the heat balance and heat efficiency of the pit shown in Fig. 1 was investigated for the case of steaming in it of unfrozen beech logs with an initial temperature $t_{w0} = 10$ °C at a degree of filling of the pit with logs, f, equal to 45%, 60%, and 75%.

As input data relating to the design parameters of the studied pit (refer to Fig. 1), as well as to the characteristics of the beech logs subjected to steaming and to the operating temperature in the pit, those specified above in Table 1 were used.

3. Results and discussion

3.1. Temperature change in logs during steaming

Figure 2 shows the change in the slowest increasing temperature in the center of the studied logs, t_{wc}, and also the average mass temperature of the logs, t_{avg}, calculated with the model (1) – (3) during logs' steaming in the pit. The operating temperature t_m changes from the initial value $t_{m0} = 10$ °C to its maximum values $t_{m1} = 70$, 80, and 90 °C within 4 hours.

In Fig. 2 it can be seen that the steaming process of the studied logs having initial temperature $t_{w0} = 10$ °C and moisture content $u = 0.6\ kg \cdot kg^{-1}$ ends as follows: after $\tau_2 = 27.0$ h at $t_{m1} = 70$ °C; after $\tau_2 = 20.0$ h at $t_{m1} = 80$ °C and after $\tau_2 = 16.5$ h at $t_{m1} = 90$ °C. At these values of τ_2, the temperature of the slowest heating central point of the logs reaches 62 °C, which corresponds to the minimum required temperature necessary to obtain quality veneer from the heated and plasticized beech logs [2, 6, 12]. At these values of the τ_2, the average mass temperature of the logs rises from its initial value $t_{w0} = 10$ °C to final average mass temperature $t_{avg\text{-}end} = 66.8$ °C at $t_{m1} = 70$ °C, $t_{avg\text{-}end} = 72.7$ °C at $t_{m1} = 80$ °C, and $t_{avg\text{-}end} = 78.62$ °C at $t_{m1} = 90$ °C.

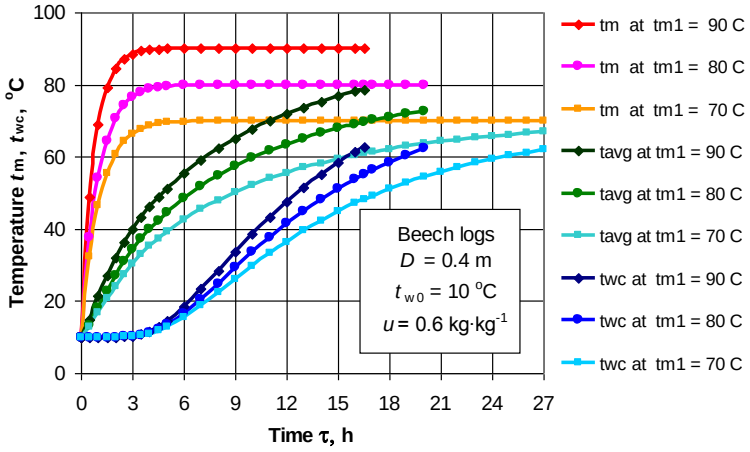

Figure 3. Change in t_m, t_{wc}, and t_{avg} of the studied logs during their steaming, depending on t_{m1}

3.2. Change in the heat balance of the pit at the end of steaming

Figure 4 presents the change of all components of the heat balance of the tested pit at its maximum possible loading level f = 75%, as well as the total energy consumption (in kWh·m^{-3}) of the pit required to carry out the entire steaming process, depending on the studied values of t_{m1}.

Figure 5 shows the change of the individual components of the pit's heat balance Q_i at f = 75% in % to the total energy consumption, $Q_{steam\text{-}total}$, depending on t_{m1}.

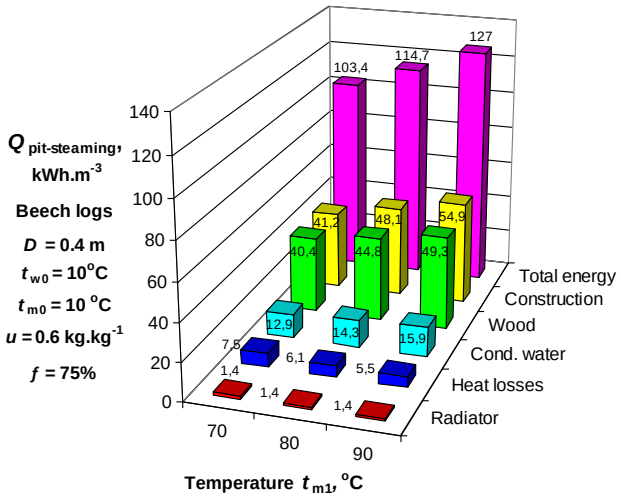

Figure 4. Change in the components of the heat balance and the total energy (in kWh·m^{-3}) of the pit required for steaming the studied logs, depending on t_{m1}

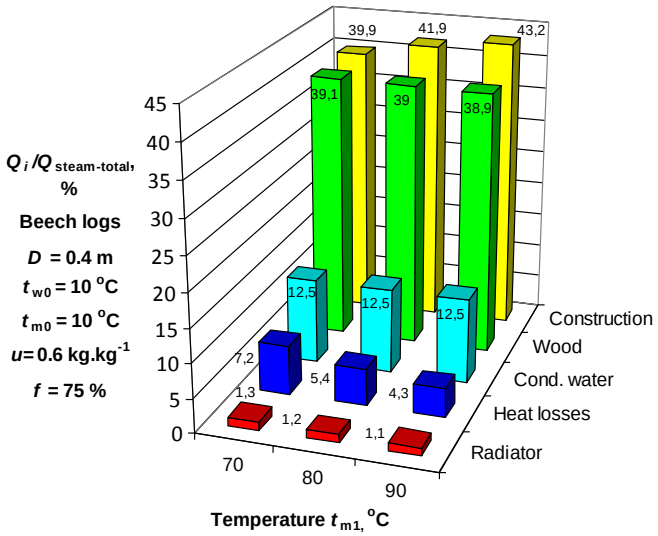

Figure 5. Change in the components of the pit's heat balance in % to $Q_{steam\text{-}total}$, depending on t_{m1}

When expressing the heat balance of the pit in kWh·m^{-3}, an increase in t_{m1} from 70 to 90 °C causes an increase in the total energy consumption of the pit from 103.4 to 127.0 kWh·m^{-3}. In this case, the individual components of the heat balance of the pit change as follows (Fig. 3): the energies Q_{Wood}, $Q_{constr.}$, and $Q_{Cond.water}$ increase from 40.4 to 49.3 kWh.m^{-3}, from 41.2 to 54.9 kWh.m^{-3}, and from 12.9 to 15.9 kWh·m^{-3}, respectively; $Q_{Heat\ losses}$ decreases from 7.5 to 5.5 kWh·m^{-3}, and $Q_{Radiator}$ remains unchanged with a value of 1.4 kWh·m^{-3}.

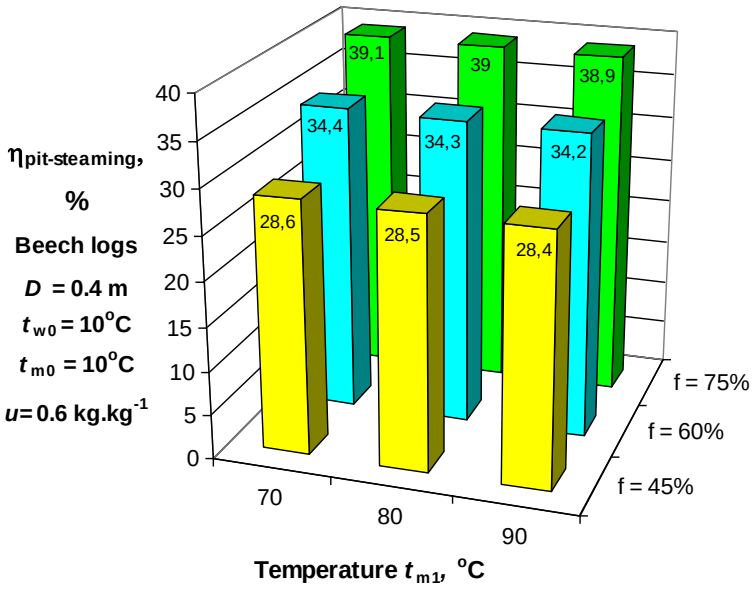

Figure6. Change in the heat efficiency of the pit, depending on t_{m1} and f

When expressing the individual components of the pit's heat balance Q_i as a % of the total energies $Q_{steam\text{-}total}$, the increase of t_{m1} from 70 to 90 °C causes the following change in the fraction of each components of this balance (Fig. 5): Q_{Wood}, $Q_{Heat\ losses}$, and $Q_{Radiator}$ decrease from 39.1 to 38.9%, from 7.2 to 4.3%, and from 1.3 to 1.1% respectively; $Q_{Constr.}$ increases from 39.9 to 43.2%, and $Q_{Cond.water}$ remains unchanged with a value of 12.5%.

3.3. Change in the heat efficiency of the pit

Figure 6 presents the change in the calculated with equation (9) heat efficiency of the pit when steaming the studied logs in it, depending on t_{m1} and f.

From Fig. 6 it can be seen that increasing the operating temperature from 70 to 90 °C causes the following insignificant decrease in the heat efficiency of the pit, $\eta_{pit\text{-}steaming}$, at a given value of the loading level:

- at f = 45%: from 28.6 to 28.4%;
- at f = 60%: from 34.4 to 34.2%;
- at f = 75%: from 39.1 to 38.9%.

Fig. 6 also shows that the reducing of the pit's loading level from 75% to 45% causes a decrease in $\eta_{pit\text{-}steaming}$ at a given operating temperature, namely:

- at t_{m1} = 70 °C: from 39.1 to 28.6%;
- at t_{m1} = 80 °C: from 39.0 to 28.5%;
- at t_{m1} = 90 °C: from 38.9 to 28.4%.

3. Conclusions

It was found that at the commonly used values of the operating temperature t_{m1} = 80 °C, the total energy consumption, $Q_{steam\text{-}total}$, of the studied pit is equal to 114.7 kWh·m^{-3} when steaming beech logs with a diameter D = 0.4 m, initial temperature t_{w0} = 10 °C, moisture content u = 0.6 kg.kg^{-1} at maximum possible loading level of the pit f = 75% aiming wood plasticizing for the production of peeled veneer.

The increase of t_{m1} from 70 to 90 °C at f = 75% causes an increase of the energy $Q_{steam\text{-}total}$ from 103.4 to 127.0 kWh·m^{-3}, i.e. by 22.8%. The fraction of the individual balance components of $Q_{steam\text{-}total}$ in this case changes as follows: Q_{Wood}, $Q_{Heat\ losses}$, and $Q_{Radiator}$ decrease from 39.1 to 38.9%, from 7.2 to 4.3%, and from 1.3 to 1.1% respectively; Q_{constr} increases from 39.9 to 43.2%, and $Q_{Cond.water}$ remains unchanged with a value of 12.5%.

The same increase of t_{m1} from 70 to 90 °C at f = 75% causes a slight decrease in the heat efficiency of the pit, $\eta_{pit\text{-}steaming}$, from 39.1 to 38.9%. The reducing of f from 75 to 45% at t_{m1} = 80 °C causes a significantly greater decrease in $\eta_{pit\text{-}steaming}$ from 39.0 to 28.5%.

The presented approach can be applied to compute the heat balance and efficiency during steaming of unfrozen logs from various wood species and with different characteristics. It could be easily modified and used to calculate the heat balance and efficiency of concrete pits of any design and construction parameters.

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Surface Modification of Wood with Plasma, to improve joint strength: A review

Selma Mujanić[1], Šljivo Umjer[1], Leila Fathi[2], Aida Kopljar[1] and Mohsen Bahmani[2]

[1] Department of Wood Science and Technology, Faculty of Technical Engineering, University of Bihac 77000 Bihac, Bosnia and Herzegovina
[2] Department of Wood and Furniture Industry Engineering, Faculty of Natural Resources and Earth Sciences, Shahrekord University, Shahrekord 64164478, Iran

E-mail: selma.mujanic@unbi.ba

Abstract. Wood modification is an important field of research aimed at improving its properties and expanding its application potential. As a natural and renewable material, wood has numerous advantages but also drawbacks such as hygroscopicity, flammability, and susceptibility to degradation, which affect its durability and functionality. This study explores plasma treatment of wood to enhance adhesion and durability. Plasma modification increases surface energy, improving adhesive bonding and resistance to external influences. The research examines plasma applications in constructions and joints. The results show that plasma treatment not only improves wood properties but also represents a sustainable alternative to traditional processing methods.

Keywords. Plasma, modification, low-pressurre, Atmospheric pressure, wood

1. Introduction

Wood represents a renewable and abundant source of energy and a naturally renewable material that is used in a variety of applications. However, in addition to its advantages, wood also has some disadvantages that affect its practical application. It is subject to decomposition due to the action of microorganisms, xylophagous insects, and ultraviolet (UV) radiation. Wood is flammable and hygroscopic, and changes dimensions with changes in water content. The mentioned disadvantages affect the application of wood to some new materials. Today, the use of non-renewable materials is high and still growing, despite the awareness that their availability is limited. The requirements for developing new technologies for the processing of renewable sources, which would replace non-renewable ones, are therefore still increasing. However, growing environmental problems are also emerging, which require the replacement of questionable materials (among which many are non-renewable) with more biologically and ecologically acceptable alternatives. As stated in the literature [1], one of the ways to avoid environmental problems arising from the use of environmentally hazardous biocides, additives, and other chemicals in formulations for the protection of wood impregnation and surface coatings is wood modification.

Today, research is being conducted daily in the world on procedures that aim to remove undesirable natural properties of wood or increase the durability of wood. One such procedure is wood modification. Wood modification is a method used to improve the properties of wood by changing its chemical nature and, in a broader sense, is a passive process in which changes in properties occur, but without changing the chemistry of the material. Wood can be modified in various ways. Wood modification is divided into passive (modification by impregnation - physical) and active (enzymatic, chemical and thermal). With each of the above wood modifications, the aim is to obtain wood with stable dimensions, resistant to the action of microorganisms, and durable, while the mechanical properties of the modified wood remain unchanged [2].

Several segments were completed throughout the work, where the goal of the work was to present the treatment of wood with plasma to obtain strong joints during gluing. The second chapter presents an overview of the most common methods of surface modification. The third chapter is dedicated to the

influence of plasma treatment in structures and other wood products. In the fourth chapter, there was talk about the application of the avalanche method in strengthening structural joints.

When it comes to improving the bonding strength of wood, it is a constant goal in the wood production process to increase the performance of wood products. Good wetting of the glue on the surface of the wood is essential for the results of solid bonding. A common technique for improving wetting and thus firm bonding is the result of sanding wooden surfaces. For example, sanding old surfaces increases surface energy, which improves humidity [3]. Also, by improving surface humidity, recently on a large industrial scale, plasma treatment has been applied, which changes the surface characteristics of wood [4]. This process results in a significant increase in surface energy, as well as an increased effect of adhesion between the substrates (elements) and the applied adhesive, which indicates increased adhesion. Wooden surfaces can be treated with plasmas from different sources, chemical or enzymatic grafting of functional molecules, coating using sol-gel methods, including deposition of nanoparticles, surface impregnation, and various mechanical procedures. The target properties that need to be improved or introduced are mainly surface activation for better adhesion and adhesion of surface coatings, humidity, and weather resistance. However, resistance to wood pests, retardancy, and mechanical properties, especially resistance to hardness and abrasion, can also be effectively improved by modifying the wood surface.

2. Current knowledge of surface treatment methods

2.1 Plasma as a physicochemical agent for modifying wood properties

The word plasma comes from the Greek word "πλάσμα", which loosely translates to self-shaping of materials. In physics, plasma is defined as an ionized (or partially ionized) gas, mostly composed of free charge carrier particles, such as ions and electrons. In essence, plasma is neutral and is considered the fourth aggregate state of matter. In nature, plasma is the most common physical state in which as much as 99% of visible matter in the universe is found, and well-known examples of plasma include: Aurora Borealis (Northern Dawn), Aurora Australis, Van Allen Belt (radiation zones), Sun, Stars, Earth's mantle, Ionosphere, etc. However, natural plasma cannot be used at the current level of technical development. For applications in research, technology, and industry, plasma needs to be produced, which is usually done by electrical discharge of a gas.

The composition of plasma depends on the gas used in plasma generation and the chemical reactions during plasma formation, which produce free electrons, ions, molecules, atoms, UV photons, metastable particles, radicals, i.e. excited neutral and charged particles that also participate in these reactions. Of course, such particles can cause modification of the substrate surface during plasma treatment [5,6].

It is known that materials are composed of atoms and molecules and that with increasing temperature they change their state from solid to liquid and further to gaseous state, which is schematically shown in Figure 1.

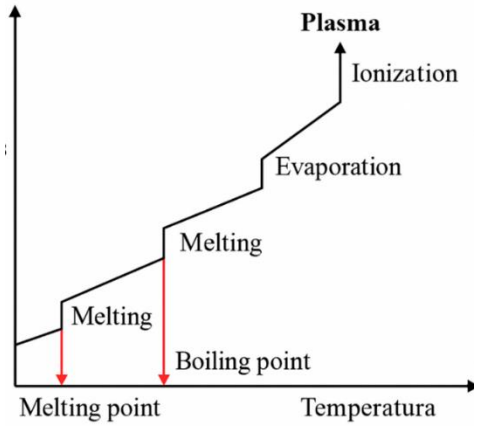


Figure 1. Presentation of the transition of the state of matter [6].

Simply put, it can be said that increasing the temperature of solid materials leads to an increasingly intense movement of parts of the molecules so that at one point they begin to leave their place determined by potential energy, the basic structure is destroyed and a transition to the liquid state occurs (eg ice crystals melt). With further heating of the material, the kinetic energy of the molecules becomes greater than their potential energy and they become freer, which leads to separation into atoms mutual collisions, and the transition to a gaseous state. As the temperature rises to more than several thousand degrees, the collisions of atoms become increasingly intense, and electrons are released from the atomic structure, resulting in the formation of particles that are charge carriers - negatively charged electrons and positively charged ions, that is, the destruction of molecules creates positive and negative atomic groups. Electrically charged particles in motion create electric and magnetic fields, which provide the energy needed for further ionization of atoms, i.e. a state of almost completely ionized substance plasma is created. In general, it can be said that plasma is created by supplying energy to the gas [6].

The forms and types of plasma are very numerous, and plasmas can be classified according to several criteria. Plasmas that occur in nature first of all differ in density (more than 10 orders of magnitude), and accordingly, the differences in physical properties are extreme. The key parameter for distinguishing technical plasma is the pressure of the neutral gas in which the ionized particles move about the atmospheric pressure. According to this criterion, plasmas are classified into low-pressure, high-pressure, and atmospheric-pressure plasmas (atmospheric plasmas). According to the temperature at which it is applied, plasma is divided into cold and hot plasma, Figure 2.

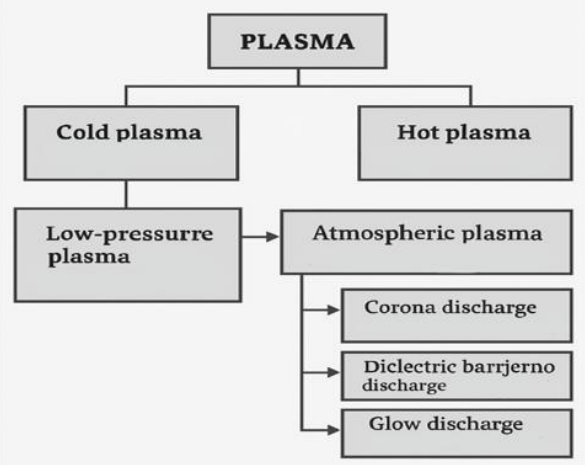


Figure 2. Presentation of the transition of the state of matter [6].

Low-pressure plasma is an example of cold or low-temperature plasma, which is also an example of non-equilibrium plasma (cold plasma, low-temperature plasma, nonequilibrium plasma), which means that the electrons in the plasma have a much higher temperature than the temperature of the heavier ion particles in the plasma. With appropriate external excitation of the gas in such a plasma, it is possible to achieve conditions where the gas temperature is close to room temperature, while at the same time, the effective temperature and kinetic energy of the electrons are significantly higher and large enough to maintain the plasma and initiate plasma-chemical reactions [7]. The temperature of electrons Te is of the order of 104 to 105 K, while the temperature of heavy particles of ions and other particles of molecules, atoms, and free radicals is close to room temperature, so the gas almost does not heat up and maintains room temperature. Therefore, such plasma is particularly suitable for processing thermally sensitive materials.

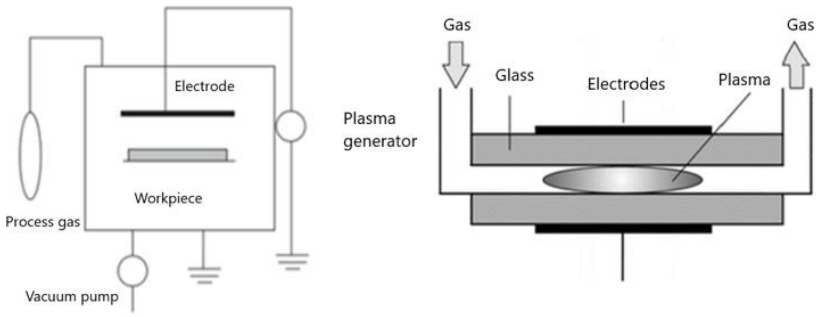
In equilibrium plasmas, there is thermal equilibrium, i.e. the temperature of electrons and heavier ionic particles is equal and, as a rule, high, and the kinetic energy of all particles is high. In surface treatment applications, such plasmas would be much more efficient in the generation of radicals and the flow of ions that reach the surface of the material. However, since they develop high temperatures due to the high degree of ionization, it is very difficult to control the energy of the particles and thus optimize the conditions for the production of specific radicals, making it impossible to process thermally unstable materials [8].

Plasma is known as the fourth state of matter and consists of a high-energy gaseous mixture of atoms, molecules, ions, free electrons, and metastable species [9]. Plasma is widely known for its ability to exfoliate polymers, and plasma marching is used commercially by the semiconductor industry for cleaning silicon, as mentioned above. Another use of plasma is to deposit a thin layer of material on a substrate. Plasma can also be used to substitute atoms on the surface of polymers.

Such reactions functionalize the surface and, for example, facilitate the finishing of plastics by making the surface more wettable [10]. Plasma used to modify wood is obtained from organic or inorganic parts. Plasma derived from organic gases or steam forms the hydrophobic surface of the wood. Likewise, when inorganic gases are used, the resulting plasma can increase the wood's surface energy and bonding ability. [11]

Atmospheric pressure plasma can be obtained in several ways. The first method is corona discharge, in which the electric discharge is caused by an electric field of high frequency or voltage, and the surface of the treated substrate is exposed to the direct action of the corona. Corona treatment is the oldest and most commonly used technique of surface treatment of materials with plasma that works at atmospheric pressure and with the surrounding air as a working gas. This plasma system, in principle, by its characteristics, is suitable for use in woodworking and other industries (width, speed, temperature).

In addition to the corona discharge, two other methods of discharge are used to obtain atmospheric plasma. These are: dielectric barrier discharge (DBD; silent discharge, SD), the system for obtaining which is schematically shown in Figure 3. and glow discharge (APGD). Glow discharge at atmospheric pressure is characterized as a uniform, homogeneous, and stable type of discharge, most often applied in gases such as helium (He) and argon (Ar), and sometimes nitrogen (N2). This type of discharge represents an alternative uniform source of cold plasma, which also has the advantage over low-pressure plasma because it operates without a vacuum, i.e. at atmospheric pressure.



a) low-pressure plasma b) atmospheric plasma

Figure 3. Schematic representation of the plasma system [12].

The low-pressure plasma system is composed of a vacuum chamber (Figure 3) in which the electrode and supports are placed, depending on the type of sample, because it involves discontinuous material processing (the size of the sample is determined by the size of the support) [13]. It is described as a controlled and reproducible technique for plasma processing which, unlike atmospheric plasma, requires a vacuum pump to achieve low pressures ranging from 0.01 to 1 mbar. Excitation by the electromagnetic field at low pressure inside the vacuum chamber causes acceleration.

Free electrons and when their kinetic energy is high enough for plasma reactions such as ionization, fragmentation, and excitation of matter to occur, plasma is created. This condition is noticed by the appearance of light (from light blue to violet color - Figure 4.). Atoms and molecules are ionized, excited, and fragmented and form a highly reactive mixture of gases which, during the processing of the material, reacts physico-chemically with the sample, resulting in changes in the properties of the surface of the processed material. The types of changes and the obtained effects primarily depend on the process gas and its physical and chemical properties, but also on the characteristics of the substrate and processing conditions.

3. Properties achieved by plasma treatment

Plasma modification of wood is a process, together with chemical and heat treatments, that are in the domain of wood modification [14]. Unlike modification techniques such as acetylation or heat treatment, plasma treatments for wood have not been commercialized. However, this new technology represents a modern approach to wood improvement, compared to conventional bulk methods used in the past to improve wood performance. Some of the commercial applications of plasma processing are in the conductor industry, where it is used to clean or coat silicon wafers, and also in the plastics industry, where plasma is used to improve the finishing of otherwise hydrophobic plastic surfaces [15].

3.1. Reactions and mechanism of action of plasma

It is necessary to ensure the transfer of energy from an external source, for the plasma formation reaction to occur, whereby the collision between electrons can be described by the following reactions:

1st excitation: $A + e \rightarrow A^* + e$
2. ionization: $A + e \rightarrow A+ + 2e$
3. dissociation: $M + e \rightarrow M \cdot + \cdot M' + e$
4. dissociative ionization: $M + e \rightarrow M \cdot + \cdot M' + + 2e\ M + e \rightarrow M \cdot + \cdot M'$
5. recombination: $M ++ e + S \rightarrow M + S$
6. dissociative recombination: $M + + e \rightarrow M \cdot + \cdot M'$
7. recombination as a result of photon radiation: $A + + e \rightarrow A + h\nu$

Plasma affects the surface of the substrate chemically and physically, with the reactions between the plasma and the surface depending on the type of gas used and its chemical properties. Wood materials exposed to such treatments undergo chemical and physical transformations related to chemical changes in the surface layer, changes in the structure of the surface layer, and changes in the physical properties of the surface layer. Plasma creates a high density of free radicals during the dissociation of molecules during electron collisions and photochemical processes. This causes the destruction of chemical bonds in the polymer surface of the fiber, resulting in the formation of new chemical species. The action of plasma on the surface of fibers and polymers results in the creation of new functional groups such as –OH, –C=O, and –COOH, which improve the wetting ability (hydrophilic effect), and can also be active centers for graft polymerization (grafting) of various molecules [15]. Therefore, plasma is primarily used for surface treatment of materials, because its action modifies only the surface properties up to a layer thickness of only a few tens of nm, leaving the basic properties of the material almost unchanged. In this way, selective modification of fiber properties is achieved, e.g., the ability to wet and dye, adhesion characteristics, etc. can be influenced, which is difficult to achieve with classical chemical processes without affecting the basic properties of the fibers thus treated. The effect of plasma on the surface of materials can be described through four groups of processes, Figure 3. [16]:

1. surface cleaning (plasma cleaning),
2. surface etching (plasma ablation or etching),
3. surface activation and modification (plasma modification),
4. deposition or polymerization (plasma polymerization).

Surface cleaning and etching using plasma is most often used in the electronics, semiconductor industry, optical industry, and in the cleaning of metals and ceramics. The mechanism of plasma action is the removal of a thin organic layer from the treated surfaces. The action of plasma during cleaning and etching of the surface of polymeric materials leads to the breaking of covalent bonds in the polymer chain. The effects of plasma in terms of surface activation and modification are particularly interesting and are used in medical technology, the automotive industry the plastics processing industry, and also in the wood industry. In this case, reactions occur between chemical groups on the surface of the substrate and chemical

particles in the plasma, which leads to the formation of new functional groups on the surface of the substrate [17]. This way of applying plasma in the wood industry can improve the wetting ability, i.e. the hydrophilicity, but also the hydrophobicity of wood materials.

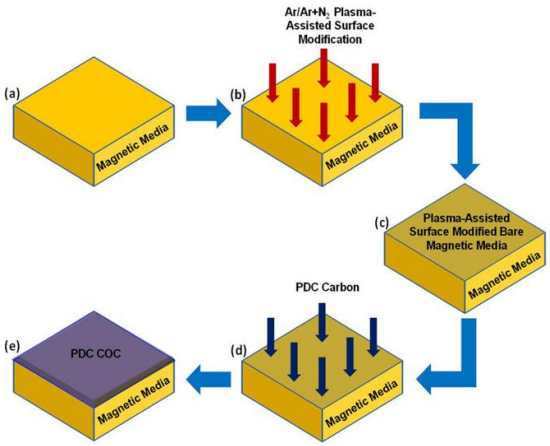


Figure 4. Schematic representation of the effect of plasma on the surface of the substrate [18].

Figure 4. shows these 4 types of action and their effects in comparison with the untreated surface of the material.

3.2. Effects of plasma modification on wood structure

The degree of durability of wood depends on its type and anatomical structure [19]. Solid wood is mainly composed of longitudinal tracheids (95%), which are hollow on all sides.

Surrounded by membranes and pointed at both ends. Simple pits connect parenchymal cells, while semi-boundary pits allow the solution to pass between both types of cells (Figure 3). After drying, the border pits can be closed or vacuumed, which hinders the permeability of the wood. Flynn reviewed permeability, fluid flow, and its relationship to anatomy in spruce wood (Picea Dietr.A.). Flynn points out that the low permeability of refractory woods is due to many interrelated factors, including:

- wood density,
- early and late wood,
- heart formation,
- tracheids,
- resins,
- cell walls.

Flynn suggests that in spruce species, the presence of abundant aspirated pits, small air sizes, and a high percentage of heartwood contribute to its natural durability. In addition, permeability and fluid flow in spruce differ between axial and lateral (radial and tangential) directions [38]. The passage through the fenced pits and beams is the main path for the lateral penetration of the coating into the soft wood. Blockage of fluid flow due to pit aspiration is greater on radial than tangential surfaces of solid wood. In juniper, the ray parenchyma cells connect through small channels a few microns in diameter with a separate membrane through which only very small plasma domes emerge, according to Liese and Bauch. In addition, the ray tracheids above and below the rows of parenchyma are "most discontinuous", and the termination of the radial penetration ends at the border of the annual ring. Marginal pits in spruce tracheids remain rampant even after air drying. However, the pits of the aerial tracheid pit membrane are invariably always heavily encrusted with exudates that block the movement of fluids across the pits into the heart [20]. The area of interconnection between the aerial tissue and the longitudinal tracheids is called the cross-field. The small size of the elliptical piceid pits (ø 2–5 μm) in spruce is another significant factor responsible for the natural persistence of spruce (Figure 5), especially in comparison with Scots pine which has large fenestriform pits (ø 10–25 μm).

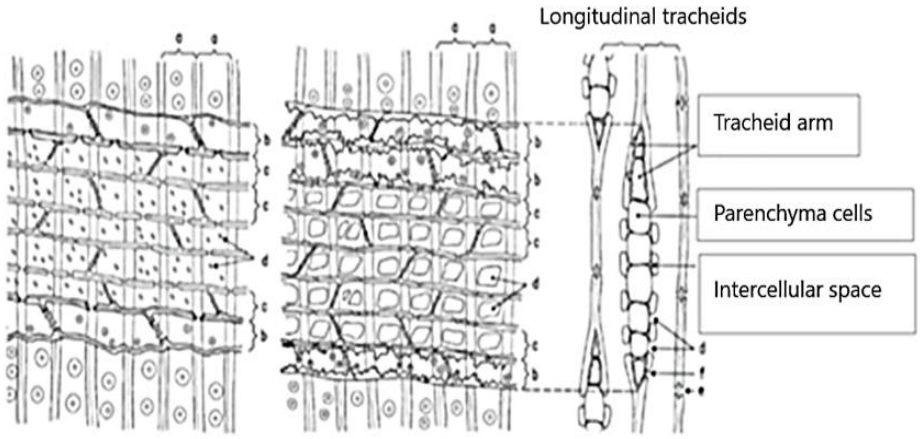


Figure 5. Radial sections of spruce (left) and radial and tangential sections of pine (middle and right) showing: (a) longitudinal tracheids; (b) rows of aerial tracheids with small enclosed pits; (c) rows of parenchyma rays with simple pits; (d) pits in cross-fields leading from the parenchyma rays to the longitudinal tracheids; (e) a border pair of pits between two tracheids; (f) a border pair between the longitudinal and aerial tracheids [21].

Plasma treatment can cut and remove membranes from border pits and enlarge the pits [22]. Prolonged exposure to plasma treatment can also create gaps in tracheid walls by etching pit boundaries and cell wall material between pits. Notching also opens rays, as well as simple and semicircular pits (Figure 6). Jamali and Evans reported that thin layers of wood layers can occur in the surface layer of wood cells. It appears that plasma treatment can reopen the main flow paths in wood, and therefore previous research has shown that plasma treatments can improve wood permeability [23].

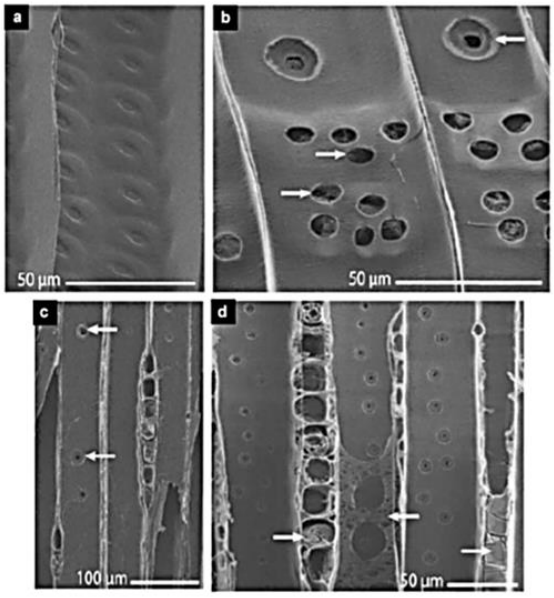


Figure 6. Radial (a, b) and tangential (c, d) longitudinal sections of California redwood (Sequoia sempervirens (D. Don) Endl) before and after plasma treatment: (a) untreated early wood showing border pits in tracheids with intact pit membrane; (b) tracheids after plasma treatment for 667s, note etching of the enclosed and semicircular egg membranes (arrow left of center) and etching of the raised boundary of the marginal fossa (arrow top right); (c) untreated early wood showing a single ray (center) and border pits in the tangential walls (arrow left of center); (d) early wood subjected to plasma treatment for 1.333 s [24].

3.3. Effects of plasma on the penetration and adhesion ability of wood

One bad feature of wood and wood-based materials is water absorption. Surface modification of wood using plasma treatment with the discharge of the dielectric barrier at atmospheric pressure has proven to be an effective method. As shown, depending on the gas used in the plasma (air, helium, nitrogen, argon), hydrophobic or hydrophilic wooden surfaces

Can be produced [1]. Wooden surfaces can be made waterproof by forming a thin film (based on ethylene or fluorine) with plasma or corona. This type of deposit can form either on bare wood or on wood coated with a coating [1]. Hydrophobic wood surfaces can also be generated with a non-equilibrium, atmospheric pressure-coated coating [1]. Some older references on plasma technology used for making wooden waterproofing can be found in a review prepared in 2002 by Podgorski et al. [25].

Plasma discharge treatment of the dielectric barrier can also improve the absorption characteristics of thermally modified beech wood, as shown by Avramidis et al [26]. The plasma treatment resulted in complete and immediate wetting of the surface of the melamine solution, which guarantees an evenly wetted surface. In this way, plasma treatment can improve the surface characteristics of the thermal modification of beech wood, which facilitates further processing, e.g. multi-layer bonding for external applications.

Chen and Zavrin [22] reported that plasma treatment could increase the permeability of wood because it expanded the "internal passages of wood". The authors reported that plasma treatment is capable of removing material from the surface of the tracheid walls, and especially from the border pits, in two ways: physical spraying and/or chemical etching. Physical dispersal refers to the "excretion" of wood fragments, while chemical etching suggests the oxidation of wood by plasma. Chen and Zavrin also noted that plasma can be generated both inside and outside the wood microstructure.

The penetration depth was deeper in samples treated with plasmas derived from inorganic gases. Wood penetration and adhesion are positively related to treatment time and strength. These findings are explained by increased surface energy and chemical changes in wood as a result of plasma treatment.

3.4. Resistance to biological degradation factors (wood pests) and antibacterial properties

Plasma treatment has also been used to improve the resistance of wooden surfaces to fungal decay. It has been shown that atmospheric pressure dielectric barrier discharge can improve the chemical reaction of biocidal quaternary ammonium compounds with wood dust and the rate of grafting of this chemical into wood. The efficiency of the reaction was improved by adding a few percentages of oxygen to the outlet of the nitrogen dielectric barrier.

3.5. The effect of plasma treatment on adhesion properties when gluing three-layer plywood

Modification of material surfaces with different discharge plasmas such as radio frequency (RF), and microwaves are well known and have long been used to increase surface free energy, wetting behavior, adhesion or maintenance, and protection of surface properties [27]. However, the Dielectric Barrier Plasma Discharge (DBD) process exploits the high reactivity of the derived reactive species at regular atmospheric pressure that is released from the boundary of the vacuum system and has large surface areas for discharge in a continuous process [28]. Meanwhile, the discharge process is easily controlled. It has high energy efficiency and wide operating pressures and voltages. Today, some DBD wood surface applications produce a shallow layer to improve water and fire protection factors.

However, DBD treatment is also useful for surface modification of wood to increase its hydrophilic character to improve its adhesive properties. Zhang et al. in their research used a veneer with dimensions of 200 × 100 × 0.8 mm that was assembled into three-layer plywood with different adhesion (the amount of glue was 200 g.mm-2) under a pressure of 1

MPa, pressing time of 5 min. Pressing temperature: MF and MUF are 1°C, and UF is 120°C. Shear bond strength tests were conducted according to ASTM D905_08 from 2013, samples were selected in each test to obtain an average value. Shear bond strength tests were performed with a mechanical testing machine (AG-10 TA) [28].

In table 1. the results of Zhang et al.'s shear strength testing of solid wood joints are presented. The table shows that samples stored for 0.5 hours after plasma treatment showed a marked increase in shear strength. The shear strength of UF wood strength increased from 0.90 to 1.05 MPa. Furthermore, the jointed wood MUF increased from 1.49 to 1.97 MPa and the wood MUF increased from 1.76 to 2.18 MPa. It showed surprisingly high shear strength. However, the shear strength of the specimen which was stored for 8 days after plasma treatment showed no difference compared to untreated wood. A slight increase in wood value may be associated with a decrease in bond strength [28].

Table 1. Display of bond strength of unmodified and plasma modified UF, MF and MUF adhesives [28].

Sample	Strength (MPa)		Lack of wood
	Seat value	Rate of increase (%)	Mean value
Untreated surface + UF	0.90	0	52
Surface modification for 0.5 h + UF	1.05	16.4	55
Surface modification for 8 h + UF	0.86	-4.4	55
Untreated surface + MF	1.49	0	60
Surface modification for 0.5 h + MF	1.97	32.2	72
Surface modification for 8 h + MF	1.52	20	66
Untreated surface + MUF	1.76	0	59
Surface modification for 0.5 h + MUF	2.18	23.8	65
Surface modification for 8 h + MUF	1.82	3.4	63

Testing the strength of joints on untreated and plasma treated wood showed the effectiveness of plasma treatment in order to increase their adhesive properties. Bond strength tests on UF, MUF and MF samples of wood adhesive bonds showed an increase in bond strength.

3.6. Five-layer plywood made of thermally modified veneer additionally treated with plasma

Impregnation of wood with melamine resin and thermal modification of wood have been well-researched, they are effective methods for increasing the stability and durability of the material. Of course, when it comes to thermal modification, certain negative properties are responsible for the reduced adhesive quality of adhesives and coatings. In recent years, efforts have been made to eliminate that problem. The application of plasma treatment is a well-known and well-used method for improving the wetting and adhesion of adhesives on various polymer surfaces. Investigations of various wooden materials have shown that exposure to plasma can increase the depth of penetration of adhesives applied to previously treated wooden surfaces. Tang et al [29] produced plywood panels using low-pressure oxygen, whereas panels made from plasma-pretreated veneer sheets showed a marked increase in shear strength.

Through this part of the paper, something will be briefly said about the research on the quality of gluing of five-layer plywood from thermally modified and undetermined beech veneers with pre-treatment with plasma and without atmospheric pressure, after exposure of plywood samples to extensive tensile stress due to the alternating hot water/drying process carried out by R. Waschera and others. When it comes to the methods and way of processing, different voltage power was used, which ensures an alternating voltage of ≈ 18 kV at the top of the electrode with a pulse repetition frequency of 15 kHz. Then a roller conveyor was used, with which the veneer was transported through the plasma zone [30]. The process gas was ambient air at atmospheric pressure, which during processing did not exceed 60°C, so thermal effects can be ruled out. The plasma treatment time was set to 5 seconds.

Unmodified and thermally modified beech veneers, dimensions (300 × 300 × 1.2 mm^3) were previously stored (72 h) at 20°C and 65% relative humidity, resulting in an equilibrium moisture content of 10% for unmodified beech and approximately 8% for thermally modified beech. Then the veneers in the

untreated state and the plasma treated state were impregnated for 1s with melamine resin in a solid content of 25% or 50% melamine solution. Impregnated veneers were dried for 24 hours and then manufactured into 5-layer plywood in a hot press (pressure force 250 N/cm^2, pressing time 3 min/mm, temperature 130-140 ° C) [30].

In the study conducted in [31], plywood produced from beech veneers that were thermally modified, pre-treated in plasma, and then immersed in melamine resin showed significantly improved bonding quality. This work [31] therefore investigated the bonding quality of plywood samples after compression/swelling. All samples were subjected to all individual cycles to allow for extreme pressure: immersion (water, 24 h, 20 °C) → immersion (water, 4 h, 100 °C) → drying (16-20 h, 60 °C) → immersion (water, 4 h, 100 °C) → cooling (water, 1 h, 20 °C) → immersion (water 72 h, 90 °C) → cooling (water, 1 h, 20 °C).

Thermally modified and unmodified beech veneers generally showed increased melamine uptake when pre-treated in plasma. To achieve an increase in melamine filling, the immersion time in melamine resins should be extended up to 900 times. Plasma-treated plywood exhibits low degradation along with increased shear strength compared to untreated sheet plywood. Impregnation with a 50% melamine solution results in a shear strength of 1.0 N/mm^2 for plywood made from pretreated plasma veneer sheets of comparable melamine loading. Plasma samples show higher shear strength. The results show that the plasma pretreatment of beech veneers is a suitable method for impregnating veneers that will be used for the production of plywood without an additional glue line with a high bonding quality that is resistant to stretching and swelling. [32]

4. Plasma treatment process

4.1. Application of plasma treatment in wood processing

Clean the planned and previously standardly prepared samples of solid wood with jet-compressed air and then expose them in a plasma reactor for 0.5-20 min. In Figure 7. shows a schematic diagram of the reactor and its various parts (a) and the purple glow of the plasma discharge inside the reactor chamber (b). First, the air valve in the reactor is opened to release any pressure inside the chamber. The top of the plate is lifted and secured to allow access to the interior of the chamber using sterile forceps. Samples are kept with sterile tweezers and placed on top of the sample container inside the chamber. The main plate lowers and the air valve closes. The vacuum pump must be in operation where the pressure inside the chamber is monitored until it reaches the desired pressure (Pa). When the desired pressure is reached at that moment, the water valve opens.

The pressure inside the chamber needs to be monitored again until it reaches the desired limit. Next, it is necessary to turn on the radio frequency (RF) unit, which is set to deliver 150 W/125 MHz of energy during the modification treatment. A purple glow develops in the chamber as shown in Figure 7. b. After we expose the wooden samples to the plasma for the desired length of time, the RF generator is turned off, the vacuum valve and the water valve are closed, and the pressure is slowly released inside the chamber by opening the air valve. The samples are carefully removed from inside the chamber using sterile forceps and taking care to avoid contact with their upper modified surface.

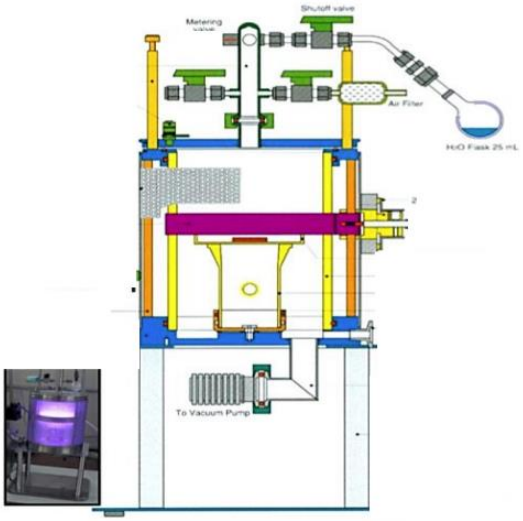


Figure 7. Reactor for treating wood with plasma [21]

After the plasma treatment of solid wood samples according to the experimental plan, thin sections are cut from the coated samples, and plasma controls and the system for testing the adhesion properties of the plasma-treated test samples are performed.

4.2. Parameters important for the effectiveness of plasma treatment

To carry out the targeted modification of the properties and achieve the desired effects by plasma processing, it is necessary to carefully determine and optimize processing parameters such as type of gas, gas flow, pressure regulated by a vacuum pump (if it is a low-pressure plasma), operating frequency of the device, processing time and distance between the electrode and the surface of the substrate. To illustrate the importance of individual parameters, the different effects achieved by plasma depending on the operating frequency range at which the modification of a substrate is carried out were previously mentioned.

4.3. Influence of the type of gas

As already mentioned, due to the high reactivity of ionized particles and radical species, the plasma affects the surface of the processed substrate chemically and physically, thus changing numerous characteristics of its surface. The types of reactions between the plasma and the surface depend on the type of gas used and its physicochemical properties.

4.4. Effect of pressure and processing time

Parameters such as pressure and time also influence changes in the physicochemical properties of the surface during plasma treatment. In the area of low pressure, the gas density is lower, the particles collide less, and the modification of the surface of the material is carried out more efficiently with minimal losses. On the other hand, very low pressure causes a relatively low concentration of radicals per unit volume. Therefore, the importance of optimizing the pressure during plasma treatment should be emphasized to achieve satisfactory results.

In areas of higher pressure (especially at atmospheric pressure and room temperature) due to higher gas density, there is a greater number of mutual collisions between particles in the gaseous state, which reduces the effectiveness of radicals and thus their ability to connect with active sites within the material.

Molecules in the air at atmospheric pressure collide with a frequency of 109 collisions per second, with an average distance between collisions of about 10-8 nm (10 nm), while at a pressure of 0.1 bar, the average distance increases to several millimetres [5]. In contrast, when processing with atmospheric plasma and with a significant increase in gas flow and processing time, there were changes.

4.5. The impact of wood modification on the environment and ecological acceptability

Today, the use of non-renewable materials is high and still growing, despite the awareness that their availability is limited. The requirements for developing new technologies for the processing of renewable sources, which would replace non-renewable ones, are therefore still increasing. But there are also growing environmental problems, which order the replacement of questionable materials (among which many are non-renewable) with more biologically and ecologically acceptable ones.

Wood is certainly among the most suitable. But we must know that even with the universal use of wood, we would not be able to solve all the problems related to the environment. For example: the use of wood as a fuel means the rapid return of carbon (carbon dioxide) to the atmosphere, which does not.

Contributes to the global reduction of the effects of carbon dioxide as a gas. We will significantly contribute to the reduction of emissions by using wood products as long as possible, in which that carbon is stored for a significantly longer time. A long lifespan is achieved by those wooden products that we use in interior spaces because they are protected from the effects of the weather or products made from naturally more durable or resistant types of wood. With less resistant types of wood, we can extend their usefulness with various protective agents or improve their durability with special processing and processing procedures.

Today, we use various means to protect wood, in all forms, because wood is an anisotropic and hygroscopic material. It is questionable how environmentally acceptable these means are, and how long are they. Also, since wood as a raw material has been exploited in large quantities, better quality types of wood are slowly running out, therefore efforts are being made to improve the properties of less resistant and lower quality types. Modified wood changes its internal structure and of course its properties, the aim is to achieve stability of its dimensions, preserve its mechanical properties, and of course achieve resistance to biotic and abiotic factors. Wood modification has already proven in practice as a successful alternative to wood protection, it has given more or less positive results as more ecologically and economically acceptable, and as a solution to the lack of better quality and more resistant types of wood.

It is concluded that great attention is paid to the protection of the environment by using modified methods of wood protection. Vegetable oils, nitrogen and water vapor (as modification media) are completely natural and environmentally friendly materials, and they can be easily recycled. The heating and curing temperatures during the thermal modification process are acceptable and not extremely high. Thermal and chemical modification are currently the most important and environmentally acceptable alternative methods of wood protection.

5.Conclusion

Plasma surface treatment has proven to be an effective and environmentally friendly method for modifying the surface properties of wood. This technique significantly improves the adhesion ability and bonding strength of wood elements, making it highly applicable in the production of engineered wood products, such as plywood and structural joints. Compared to conventional surface treatments, plasma treatment offers several advantages, including increased surface energy, improved wettability, and the potential to enhance resistance to biological degradation and weathering—without negatively affecting the mechanical integrity of the wood. Experimental results and reviewed literature confirm that both atmospheric and low-pressure plasma treatments can alter the wood surface at the micro and nanoscale, enabling better penetration of adhesives and protective coatings. Plasma also supports eco-sustainable approaches to wood modification, as it reduces the need for synthetic chemicals and hazardous substances typically used in wood preservation and adhesion enhancement. Although not yet widely commercialized in the wood industry, plasma technology shows strong potential for future application, particularly in the production of durable, high-performance wood products. Continued research and development are expected to optimize the processing parameters and expand its industrial use.

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Analysis of Regulation (EU) 2024/3012 establishing a Union framework for the certification of permanent carbon removals, carbon management and carbon storage in products of 27 November 2024 with a focus on the wood industry

Aida Kopljar[1] and Igor Stankić[2]

[1] University of Bihać, Faculty of Technology; dr. Irfana Ljubijankića bb, Bihać, Bosnia and Herzegovina
[2] Department for renewable energy sources and environmental protection, Energy Institute Hrvoje Požar, Zagreb, Croatia

*E-mail: aida.kopljar@gmail.com; istankic@eihp.hr

Abstract. Regulation (EU) 2024/3012 was adopted in response to the urgent need to regulate carbon removals, with the aim of achieving climate neutrality in the EU by 2050. The Regulation standardises carbon certification and the carbon market, enables permanent carbon removals, reduces the risk of temporary solutions and increases investor confidence. It encourages sustainable resource management and innovation in wood, agriculture and industrial production, and enables industries to develop business models based on carbon storage, opening up new economic opportunities. The adoption of this Regulation represents a key step towards a sustainable, carbon-negative economy, in which carbon removal becomes an important part of the global fight against climate change. The Commission will develop a set of certification methodologies tailored to the main types of carbon removal activities to ensure the correct, harmonised and cost-effective implementation of the EU quality criteria for carbon removal. Wood products have many environmental advantages over non-wood alternatives, and documenting and disclosing these facts helps the future competitiveness of wood when considering the impacts of climate change. The production of wood products requires less fossil fuel than alternative non-wood construction materials such as concrete, metals or plastics. Wood is naturally composed of carbon that is captured from the atmosphere during the growth of the tree. These two effects - substitution and sequestration - are why the carbon impact of wood products is favourable. The aim of this paper is to analyse how the principles and quality criteria of the Regulation can be applied to the wood industry through concrete examples of permanent carbon removal, carbon management and carbon storage in products.

Keywords: permanent carbon removal certification, carbon management, carbon storage in products, wood products.

1. Introduction

Regulation (EU) 2024/3012 (1) establishing a Union framework for the certification of permanent carbon removal, carbon management and carbon storage in products was adopted in response to the urgent need to regulate carbon removal with a view to achieving climate neutrality in the EU by 2050. As a first step, the European Commission proposed on 30 November 2022 a regulation establishing a voluntary EU-wide framework for the certification of high-quality carbon removal as part of the European Green Deal. The Circular Economy Action Plan (2020) announced that the Commission would develop an effective regulatory framework for the certification of carbon removal to incentivise carbon removal and increase carbon circularity, while respecting biodiversity objectives. The Regulation complements the climate and energy proposals of the '55% Ready' legislative package (2), in particular the Regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry into the 2030 climate and energy framework, known as the LULUCF Regulation (3), and the revised Directive on the promotion of the use of energy from renewable sources. (4) Strong interlinkages with the Commission's initiatives to

increase the climate resilience of EU forests, restore degraded ecosystems, promote the bioeconomy including the use of sustainable wood products, while fully respecting ecological principles that promote biodiversity. After three rounds of negotiations, the EU reached an agreement on the final form of the Regulation on 20 February 2024. Four years after the entry into force of the Regulation, an electronic register will be set up at EU level to ensure transparency and full traceability of the so-called certified units, which will contain information on the net carbon benefits achieved by certified carbon removal and land emission reduction activities.

The reasons for adopting Regulation (EU)2024/3012 on the certification of permanent carbon removal are:

a) *Climate change context and EU objectives*: The European Union adopted Regulation (EU) 2024/3012 to establish a reliable framework for the certification of activities that contribute to the permanent removal of carbon from the atmosphere. This is crucial in achieving the climate neutrality objective by 2050, as defined in the European Green Deal and the European Climate Law (Regulation (EU) 2021/1119). (5). Although reducing greenhouse gas emissions is the primary objective of EU climate policy, scientific research shows that reducing emissions alone will not be sufficient to limit global warming to 1.5°C above pre-industrial levels. It is therefore necessary to actively remove existing CO2 from the atmosphere.

b) *The need for standardisation and regulation of the carbon market*: Before the adoption of this Regulation, the carbon removal market in the EU was fragmented and uneven, with different methods and standards used to measure, report and verify carbon removed. This led to several problems: (a) Lack of transparency: there was no single methodology for quantifying carbon permanently removed. (b) Risk of "greenwashing": some projects claimed to remove carbon, but without rigorous scientific support or long-term verification. (c) Limitations to the credibility of the carbon market: investors and companies did not have clear rules on how to invest in carbon removal projects. By introducing clear quality criteria, the Regulation ensures trust in certified projects and enables the development of a reliable market for carbon removal.

c) *Contribution to the sustainable management of natural resources*: The Regulation recognises the importance of forests, soils and oceans as natural carbon sinks and will encourage activities that: (a) Increase carbon sequestration in agriculture and forestry (b) Reduce soil degradation and deforestation (c) Enable permanent carbon storage in wood products and innovative materials.

d) *Increase the competitiveness of the European economy*: The establishment of a regulated market for carbon removal certificates allows companies to: (a) Monetise their carbon removal efforts through the sale of certificates (b) Attract investment in carbon removal projects, including innovative technologies such as direct carbon capture (DAC) and permanent storage of CO2 in geological formations (c) Ensure regulatory compliance with future EU climate policies, including potential emissions offsetting obligations for high-emitting industries.

e) *Ensuring long-term climate impacts:* One of the key problems of previous carbon removal initiatives has been the short-term impact of many methods. The regulation ensures that certificates are only issued for long-term carbon removal, thus avoiding a situation where the removed carbon could quickly end up in the atmosphere again. Examples of long-term solutions that the Regulation encourages:

- Storage of CO2, in geological layers (durability > 1,000 years),
- Use of wood in the construction industry (durability 50-100 years),
- Production of biochar.

By introducing these criteria, the EU ensures that certified projects really contribute to climate neutrality, and not just a temporary reduction in emissions.

The wood industry plays a key role as a sector with high potential for long-term carbon storage in products and contribution to carbon sequestration through sustainable forest management, strategies for permanent carbon removal and its storage in products. Regulation (EU) 2018/841 on the inclusion of emissions and removals of greenhouse gases from land use, land conversion and forestry (3) is included in the framework for climate and energy policy until 2030, and in Article 9, titled Accounting for wood products, it states that the calculations regarding wood products of the member states show the emissions and removals resulting from changes in the carbon stocks of wood products in the following categories, (a)

paper; (b) wooden boards; (c) sawn timber. By applying the first-order decay function, methods and default half-life values for wood products. Default half-life values: The half-life value means the number of years required for the amount of carbon stored in a wood product category to be reduced to half its initial value. The default half-life (HL) values are: (a) 2 years for paper; (b) 25 years for wood-based panels; (c) 35 years for sawn timber.

2. About the Regulation

The general objective of the Regulation on carbon removal certification is to promote high-quality carbon removals in support of the 2050 climate neutrality objective. The specific objectives of the proposed Regulation on carbon removal certification include:

a) *establishing four quality criteria* (**QU.A.L.ITY**): **qu**antification, **a**dditionality and baselines, **l**ong-term storage and sustainabil**ity** for the identification and certification of high-quality carbon removals achieved in the EU;
b) *developing certification methodologies* tailored to each type of carbon removal activity in order to promote the consistent and correct implementation of the QU.A.L.ITY criteria;
c) *increasing public trust in carbon removals* by ensuring the transparency and reliability of the certification process, including through certification schemes recognised by the Commission and public carbon removal registries.

The Regulation affects economic operators such as farmers and foresters, but also industrial companies that will develop carbon removal activities on the ground, and private organisations and Member State bodies, which may develop private or public certification schemes to implement and control the certification process. The Regulation is a voluntary Union framework for carbon removal certification by establishing:

2.1 Quality criteria for carbon removal activities carried out in the Union;

Quantification; The carbon removal activity must deliver a net carbon removal benefit, which is quantified using the following formula:

net carbon removal benefit = UBaseline – UTotal – SPIncrease > 0

where:

(a) UBaseline is the amount of carbon removals in accordance with the baseline;

(b) UTotal – the total carbon removals under the carbon removal activities;

(c) SPIncrease – the increase in direct and indirect greenhouse gas emissions, excluding those from biogenic carbon sinks in the case of carbon sequestration in agriculture, resulting from the implementation of the carbon removal activities.

They are indicated by a negative sign (−) for net greenhouse gas removals and a positive sign (+) for net greenhouse gas emissions, and are expressed in tonnes of carbon dioxide equivalent. The operator shall collect data on carbon removals and greenhouse gas emissions in a manner consistent with national greenhouse gas inventories.

Additionality; The carbon removal activity must be additional and to this end the carbon removal activity must meet both of the following criteria: (a) it must go beyond Union and national legal requirements; (b) it is carried out for the incentive effect of the certification. Carbon removal activities should be additional and must represent a real and additional reduction or removal of emissions compared to what would have occurred in the baseline scenario. Certification therefore refers to additional efforts by the operator and is not intended for activities that would take place in a business-as-usual scenario, e.g. because the activity is already taking place, is required by law or national policy. In the case of an activity that has a better performance than the standardised baseline, the additionality criteria are considered to be met. Most methodologies ensure that the project does not need to be listed on the positive list; if the project meets the requirements, it is considered eligible. Some methodologies also require specific reporting or testing to demonstrate additionality (e.g. Zertiforest or FSC). The Commission's next steps should be to define and quantify additionality for forestry activities.

Long-term storage; The operator must demonstrate that the objective of the carbon removal activity is to provide long-term carbon storage. For the long-term storage criteria, four aspects of the methodologies must be defined: a) the activity period; defined as the period that has ended, the activity is generating a net benefit, and the length is specified in the applicable certification methodology. For carbon farming activities, the activity period should last at least 5 years. Activity periods may vary for different forest activities. Most methodologies require monitoring of carbon stocks during the certification project, ranging from annually (e.g. FSC) to 5-year intervals (e.g. EVA) or 10/12-year intervals (e.g. Woodland Carbon code or SNK). b) the monitoring period; is the period during which carbon storage is monitored by the operator. During the activity, units with a certain shelf life are created (temporary carbon removal units). Monitoring should ensure that carbon remains stored during and after the activity.

For example, a forestry activity takes place from 2025 to 2035 and the monitoring period lasts 20 years (i.e.10 years after the activity period); the carbon removal units are therefore valid until 2045. Therefore, monitoring must continue at least until 2045 to ensure that the carbon removed by the activity from 2025-2035 is still stored. But no new units will be created between 2035 and 2045. Most methodologies require monitoring of carbon stocks during the certification project, ranging from annually (e.g. FSC) to 5-year intervals (e.g. EVA) or 10/12-year intervals (e.g. Woodland Carbon code or SNK). It remains an open question whether each forest carbon removal activity should have its own minimum monitoring period. In the case of carbon sequestration in agriculture and carbon storage in products, the carbon stored within the carbon removal activity is considered to be released into the atmosphere at the end of the monitoring period. c) monitoring requirements; therefore, monitoring must monitor and mitigate any risk of release of stored carbon during the monitoring period; d) rules for liability mechanisms; Monitoring of long-term storage must be subject to appropriate liability mechanisms for any release of stored carbon during the monitoring period.

Sustainability: The carbon removal activity must have a neutral impact or provide indirect benefits for all of the following sustainability objectives: (a) climate change mitigation that goes beyond the benefit of net carbon removal. The activity must meet minimum sustainability requirements, (b) climate change adaptation; (c) sustainable use and protection of water and marine resources; (d) transition to a circular economy, including the efficient use of biomaterials obtained from sustainable sources; (e) pollution prevention and control; (f) protection and restoration of biodiversity and ecosystems.

2.2 Rules for verification and certification of carbon removals;

The operator must apply certification methodologies to meet the criteria (quantification, additionality, long-term storage and sustainability) by establishing technical certification methodologies for activities related to permanent carbon storage, carbon sequestration in agriculture and carbon storage in products. For carbon management activities, it is assessed whether the activities contribute to the sustainable management of agricultural land, forests and the marine environment. For carbon storage in products, certification methodologies for wood-based construction products and bio-based construction products are preferred. Carbon removal claims made by operators will have to be regularly monitored, reported and independently verified by certification bodies. These reports will be publicly available in the registers of certification schemes and will contain a significant amount of information on the effects of the proposed regulation. The data it collects will be one of the main sources of information on the basis of which progress in the implementation of the proposed Regulation will be assessed and its implementation will be monitored through annual reports of certification schemes recognised by the Commission.

For certification of compliance with this Regulation, the operator shall apply to a certification scheme/scheme. The minimum information to be provided in the certificate shall be: the name and type of carbon removal activity, the name and contact details of the operator; the location of the carbon removal activity, including a geographically explicit location of the activity boundary, in accordance with the requirements for a scale of 1:5000 for the Member State concerned; the start date and end date of the carbon removal activity; the name of the certification scheme; a reference to the applicable certification methodology; the net carbon removal benefit; the carbon removals in line with the baseline; the duration

of the monitoring period of the carbon removal activity; the increase in direct and indirect greenhouse gas emissions, the total carbon removals.

2.3 Rules for the operation of certification schemes and the rules on the basis of which they will be recognised.

After acceptance of the application, the operator shall submit to the certification body a comprehensive description of the carbon removal activities (activity plan) including evidence of compliance and the expected net carbon removal benefit or expected net emission reduction benefit, and a monitoring plan, including the certification methodology applied, in order to assess compliance and the total expected amount of carbon removed and the net carbon removal benefit. The operator shall support the certification body during audits for certification and re-certification purposes, by providing access to the locations where the activity in question is carried out and by providing relevant data and documentation.

Certification bodies appointed under a certification scheme must be accredited by national accreditation bodies, while Member States shall supervise the work of the certification bodies. In order to demonstrate compliance with this Regulation, the operator shall use a certification scheme recognised by the Commission, and the certification schemes shall be implemented on the basis of reliable and transparent rules and procedures. At least every five years, or more frequently, the certification body shall carry out recertification audits to reconfirm the compliance of the activity and to verify the net removal benefit or net emission reduction benefit achieved by the activity. The Commission shall establish a Union Registry for the permanent removal, management and storage of carbon in products and certification registries by 27 December 2028 and shall thereafter duly maintain that registry in order to publish information related to the certification process in an accessible manner. The Union Registry shall be financed by annual fixed fees paid by users.

Registries shall issue certified units only after the net removal or reduction benefit has been achieved on the basis of a valid certificate of compliance resulting from a recertification audit. No certified unit may be issued more than once and may not be used by more than one natural or legal person at any time. Carbon sequestration units and carbon storage units in the product expire at the end of the activity monitoring period and are deleted from the certification register unless long-term storage of the removed carbon is demonstrated through ongoing monitoring, in accordance with the rules in the certification methodology. Permanent carbon removal units, sequestration units in carbon management, carbon storage units in a product and land emission reduction units are different from each other.

Carbon removal activities have a high potential to provide sustainability solutions that benefit everyone, therefore it is appropriate to set minimum sustainability requirements to ensure that carbon removal activities have a neutral impact or generate indirect benefits. Those sustainability requirements should, where appropriate and taking into account local conditions, be based on the technical verification criteria for no significant harm to forestry activities and underground permanent geological storage of CO2 set out in Commission Delegated Regulation (EU) 2021/2139 (8) and on the sustainability criteria for forest and agricultural biomass feedstock set out in Article 29 of Directive (EU) 2018/2001. (4) Practices such as forest monocultures that have a detrimental impact on biodiversity should not be eligible for certification. The Regulation covers the following activities across the EU:

a) permanent carbon removal (atmospheric or biogenic carbon) refers to human activities that remove CO2 from the atmosphere and store it safely and permanently for several centuries.
b) Some examples include: Direct Carbon Capture from Air with Storage (DACCS); Bioenergy with Carbon Capture and Storage (BECCS) and other biomass-based methods (BioCCS); Permanent chemical fixation of CO2 in products; Other technological solutions leading to permanent storage.
c) carbon storage activities that capture and store carbon in long-lasting products for at least 35 years (such as wood-based construction products);

d) carbon management activities that enhance carbon sequestration and storage in forests and soils or that reduce greenhouse gas emissions from soils for a period of at least five years (e.g. reforestation, restoration of peatlands or wetlands, etc.).

Detailed certification methodologies for individual carbon removal activities will be developed in order to apply the quality criteria set out in this Regulation in a standardised, verifiable and comparable manner.

3. Implementation of the Regulation in the wood industry and future potential for further use

The carbon emissions saved per unit of wood product used are based on: (1) gross carbon dioxide (CO2) emissions from the production of wood products; (2) CO2 from biofuels burned and used for energy during production; (3) carbon stored in the final product and (4) fossil CO2 emissions from the production of non-wood alternatives. The results show significant carbon emission savings when wood products are used in building construction instead of non-wood alternatives. The wood industry can contribute to carbon removal and storage in three main ways: (a) sustainable forest management and carbon sequestration in forest ecosystems; (b) extending the life of wood products and (c) using wood products to replace materials with a higher carbon footprint. These approaches are subject to the quality criteria of the Regulation: quantification, additionality, long-term storage and sustainability.

3.1 Sustainable forest management and carbon sequestration

Example: Certified sustainable forest; Forests act as natural carbon sinks, absorbing CO2, from the atmosphere through photosynthesis. Certification according to the Regulation may include: Afforestation and replanting: Planting of fast-growing species (eg poplar, pine) that quickly absorb CO2; Sustainable forest management: Application of selective logging, protection of old trees and increase in biomass density; Increasing soil carbon stocks: Agroforestry and soil erosion protection to increase carbon sequestration in underground roots and organic matter.

Quantification and certification: The regulation requires accurate measurement of the amount of carbon absorbed by the forest ecosystem. This is done using satellite monitoring, field measurements of biomass and carbon cycle modeling. Long-term storage: Ensuring that wood is not used for short-lived products with rapid CO2 release (e.g. paper, pellets for combustion), but for long-lasting products such as construction timber.

3.2 Extending the life of wood products

Cascading is defined as the efficient use of the same resources for multiple consecutive uses to increase the overall availability of biomass within a given system, and industrial residues represent a much greater quantitative potential for cascading. Resources, including residues from wood processing and waste resulting from the use or consumption of wood-based products, should be used, first as recovered materials and finally as energy, thereby multiplying the benefit created by a single unit of resource. Recycled fibers from forest-based industries are used, for example, in the paper, cardboard and clothing industries. Cascading wood use, as well as the diversification of forest-based businesses, can generate increased added value or growth opportunities further down the value chain in the long term.

3.3 The cascading use of wood materials in construction is increasing

The collection of construction wood material and waste and their preparation for reuse or recycling depends on the quality and availability of the collected waste wood, which is hampered, for example, by pollution due to the previous use of preservatives, paints and glues, the lack of original separation of wood for demolition, the lack of economically feasible ways of cleaning specific fractions of waste wood and legislation (Vis et al. 2016). (7) The increasing cascading use of wood materials in construction has been found to have the potential for CE marking in Finland (Häkämies and Lehtonen, 2019). (8) Wood has the greatest growth opportunities in residential buildings, as well as in public, garden and environmental construction. Buildings made of wood can permanently store carbon that would otherwise be released through biomass decomposition or combustion.

Cross-laminated timber (CLT): Replacing concrete and metal structures with timber structures in many different applications leads to a reduction in the CO2 emissions associated with their production. Using timber as a structural material in residential buildings instead of concrete and steel could lead to a reduction in concrete consumption of 35-56% for single/two-family houses and a reduction in concrete consumption of 9-48% for multi-storey buildings, as well as a reduction in steel consumption of 25% for residential buildings. In Germany, it has been estimated that 26% of the collected timber is suitable for reuse, and 27% could be directed to other high-value secondary applications originating from the building stock (Höglmeier et al., 2013). (9)

Extending the lifespan of buildings and renovations: A combination of adaptive buildings, long-lasting construction solutions and improved maintenance could increase the average lifespan of buildings by 40%. Modular design could increase the average lifespan of new buildings by 5% by 2030 and 20% by 2050 (Cambridge Econometrics, 2018). (10) For example, in long-term construction, emphasis is placed on the design phase and the quality and repairability of building materials and structures.

3.4 Increasing the cascading use of wood-based materials in the forest industry (including recycled fibres)

Increasing material efficiency (in production) or material efficiency refers to the economical use of natural resources at the operator level, the effective management of side streams and the reduction of waste. In general, recycling of materials at different stages of the life cycle is also part of material efficiency, as is the replacement of non-renewable raw materials with wood-based solutions. Wood can be used to produce bioplastics, textiles and other products that otherwise require fossil fuels, such as: cellulose fibres (e.g. Tencel, Lyocell) as an alternative to synthetic fibres from petroleum or lignin-based bioplastics as a replacement for traditional plastics. Wood composites as a replacement for aluminium and steel in the automotive industry. Highly durable wooden furniture or extending the life of wooden products through design, recycling and reuse (e.g. furniture restoration instead of disposal). Quantification: measuring the amount of carbon contained in finished products and estimating their expected lifespan. Additionality: Producers can obtain certificates only if they can prove that without this initiative the wood would be used for products with a short life span or would be burned, which would release CO2, back into the atmosphere. Wood products can contribute significantly to carbon storage if used as a long-term building material. Long-term storage: by ensuring that wood is not used for disposable products that will quickly end up in landfills or incinerators. Certification: certification of long-term carbon storage according to the criteria of the Regulation, for example, can be based on a life cycle comparison (LCA-Life Cycle Assessment) between wood-based products and their conventional equivalents. Sustainability: existing certification systems.

3.5 Certification systems

The wood industry can use existing certification systems as a basis for certification under the Regulation: (a) FSC (Forest Stewardship Council) and "(b) PEFC (Programme for the Endorsement of Forest Certification) (c) EPD (Environmental Product Declaration) for wood construction products, (d) LCA analyses and the ISO 14064 standard for carbon quantification.

3.6 National strategies and financial incentives

Member States can implement incentives for the sector through: (a) Tax breaks for certified products with long-term carbon storage. (b) Subsidies for afforestation and sustainable forest management. (c) Funds for research and development of innovative wood materials.

4. Conclusion

The Regulation establishing a Union framework for carbon removal certification (EU/2024/3012) was published in the Official Journal of the EU on 6 December 2024, creating the first voluntary framework at EU level for the certification of carbon removal, cultivation and storage in products across Europe. By establishing EU quality criteria and setting out a monitoring and reporting process, the Regulation will facilitate investment in innovative carbon removal technologies as well as sustainable carbon cultivation solutions. The carbon removal certification framework will incentivise innovative carbon removal

technologies and cultivation that contribute to the EU's climate, environmental and zero-pollution objectives and will help the EU achieve climate neutrality. It establishes certification rules for:

a) Carbon cultivation, such as forest and soil restoration and avoidance of emissions from soil, peatland rewetting, more efficient use of fertilisers and other innovative agricultural practices;
b) Industrial carbon removal, such as bioenergy with carbon capture and storage or direct carbon capture and storage from the air;
c) Carbon sequestration in long-lasting products and materials, such as wood-based building materials or biochar.

The regulation will improve the EU's capacity to quantify, monitor and authenticate all these forms of carbon removal. In particular, it establishes rules for the recognition of certification schemes that demonstrate compliance with the EU framework and a specific set of criteria to ensure high quality carbon removal through transparency and credibility of the certification process.

An EU registry will be established to create a high level of transparency on certified carbon removal. This will be established within 4 years. In the meantime, registries of existing certification schemes can be used. The regulation prioritises the certification methodologies that should be developed. On this basis, the Commission, with the support of the Carbon Removal Expert Group, will continue its work on developing credible and tailored certification methodologies for different types of carbon removal activities.

Certified carbon sequestration can be the basis for new economic opportunities and can be monetized through private schemes and public sector support, as well as by creating commercial advantages for consumers who want to reward environmentally friendly practices. Carbon farming will create new business models for farmers and foresters and is expected to bring significant benefits for biodiversity. The agreed regulation also encourages the use of long-lasting bio-based construction products to retain carbon for decades or longer, encouraging new sustainable construction techniques. The certification process is based on certification rules and includes the following steps:

a) Participation in a certification scheme: Operators apply for an EU-recognised scheme, submitting activity and monitoring plans.
b) Certification audit: The certification body checks the compliance of the activities with EU criteria and methodologies, issuing a certificate of compliance.
c) Recertification audit: Regular audits ensure that the activities are correctly implemented and that carbon removals or emission reductions are generated in the soil.
d) Certificate registry: All information about the certificate, including the amount of certified units, is published in a registry (established by 2028). Until then, certification schemes will maintain their own registers.

As regards financial support for carbon removal technologies, the Regulation unlocks innovative private and public financing, including impact financing or results-based public support, as carbon removers and carbon farmers can be rewarded based on certified removals and emission reductions. It will also support a new European Bauhaus by recognising the carbon storage capacity of bio-based and energy-efficient building materials. The Commission will continue to finance carbon removal through various programmes, such as the Innovation Fund, the Common Agricultural Policy, the Regional Development Fund, the LIFE programme and the Horizon Europe programme (including the Soil Deal for Europe mission).

The contributions of forests, forestry and wood use to climate change mitigation are multiple and complex, and broadly speaking, there are several ways in which these contributions affect climate change and climate change mitigation:

a) *Forest carbon sequestration*. Forest ecosystems can sequester carbon by removing CO2 from the atmosphere through photosynthesis and tree growth, releasing oxygen and storing carbon in trees and other vegetation, dead wood, litter and soil.
b) *Greenhouse gas emissions*. Forest ecosystems can release stored carbon back into the atmosphere through deforestation, degradation, logging and natural disturbances, as a result of decomposition or combustion. However, there can also be non-CO2 greenhouse gas

emissions associated with forest ecosystems, including emissions of methane (CH4) and nitrous oxide (N2O), particularly from biomass that is burned.

c) *Carbon storage of wood products*. Wood derived from forests can retain carbon that was originally re- moved from the atmosphere of forests in the form of wood-based products; although this carbon is released into the atmosphere when the products are disposed of at the end of their life. Disposal may also involve methane emissions under certain conditions if wood products are disposed of in the ground.

d) *Substitution of greenhouse gas intensive materials*. The use of wood-based products and wood fuels can be avoided or re-enabled by the use of alternative non-wood products and fossil energy sources, the production of which uses and disposal of which may involve higher greenhouse gas emissions than equivalent wood products.

The Commission, with the support of the Carbon Removal Expert Group, will establish tailored EU certification methodologies for different carbon removal activities by means of delegated acts. These acts include standard procedures, involving the European Parliament, the Council and wider stakeholders.

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Using Beech Timber Steaming Condensate in Wood-Based Panel Production

Milica Rančić*, Ivana Gavrilović-Grmuša, Nebojša Todorović, Mlađan Popović, Marko Veizović and Goran Milić

Department of Wood Science and Technology, University of Belgrade – Faculty of Forestry, Belgrade, Serbia

*E-mail: milica.rancic@sfb.bg.ac.rs

Abstract. Steaming of timber is a common pre-drying process for many hardwood species, especially beech. It is primarily used for color change but can also improve certain drying characteristics. However, the process generates large volumes of condensate, which is typically treated as wastewater, despite its potential as a valuable by-product. This study focuses on the condensate obtained during the direct steaming of beech timber, collected after 12 hours of steaming at 98 °C within a 30-hour total process. The chemical profile of the condensate was analyzed using LC-MS chromatography, along with measurement of its total phenolic and flavonoid content. Based on its chemical composition, the condensate was evaluated as a potential environmentally friendly additive in urea-formaldehyde (UF) adhesives used for wood-based panel (WBP) production. Panels prepared with UF resin modified by the condensate showed reduced formaldehyde emissions compared to those produced with unmodified UF resin. This improvement can be attributed to the high content of phenolic and flavonoid compounds present in the condensate. The results indicate a promising opportunity for repurposing steaming condensate as a sustainable component in adhesive systems for the wood industry.

1. Introduction

Wood-based composite panels (WBP) such as particleboard, oriented strand board (OSB), and medium-density fiberboard (MDF) have seen consistent growth since the mid-20th century, primarily due to their adaptability, cost-efficiency, and broad application across construction, furniture, and packaging industries. These panels are typically manufactured from low-grade wood and sawmill by-products, raising concerns about long-term raw material sustainability.

Steaming of wood—especially beech, a key hardwood in Europe—is widely practiced to improve aesthetics and reduce internal stress. This hydrothermal process also alters wood chemistry, degrading cellulose, hemicellulose, and lignin [1], and generating condensate rich in water-soluble extractives [2]. While beneficial for timber quality, the resulting condensate poses environmental challenges if left untreated [3,4]. However, its chemical composition offers potential for value-added applications, such as in wood adhesives for WBP production.

Urea-formaldehyde (UF) resins dominate the wood-based panel industry due to their strong adhesion, low cost, and favorable curing properties [5]. Commercial UF resins are diluted with deionized water to adjust viscosity for optimal blending [6]. Substituting this water with beech condensate could influence resin curing and performance due to the condensate's acidity and reactive compounds. Though limited, prior studies indicate that condensates from hydrothermal treatments can enhance UF and MUF resin properties and act as formaldehyde (F) scavengers [7-9]. The authors have already studied influence of beech wood steaming condensate (BSC) on curing behavior of standard and condensate-modified UF resins using FTIR and DSC analyses [10]. The results indicated that phenolic compounds in BSC altered UF resin curing by lowering peak temperatures and increasing activation energy, suggesting enhanced reactivity. BSC thus offers a sustainable, low-cost alternative to deionized water in UF adhesive formulations for wood-based panel production. This study further investigates the feasibility of using beech steaming condensate as a sustainable additive in UF adhesive formulations for WBP production.

2. Materials and methods

2.1 UF resin

Commercial UF resin (UF) was provided by a domestic company Kronospan Srb (Lapovo, Serbia). Ammonium chloride, sodium hydroxide, sodium sulfite, sodium acetate, hydrochloric acid, sodium carbonate, and methanol were purchased from Centrohem (Serbia). Folin-Ciocalteu reagent, gallic acid, and quercetin were purchased from Sigma Aldrich Chem (Steinheim, Germany). All chemicals and reagents were of p.a. grade and used without further purification. The condensate (BSC) was obtained from the so-called direct steaming process of beech wood.

2.2 Steaming

The direct steaming process was conducted on 50-mm beech wood timber (*Fagus sylvatica* L.) in an industrial chamber (capacity of 30 m^3). Steam produced in the steam boiler was consistently fed directly into the chamber, leading to the continuous condensation and subsequent discharge of the beech wood steaming condensate (BSC). The condensate was collected during steaming at 98 °C within a 30-hour total process. A 2-liter sample of condensate was collected approximately 12 hours into the steaming process and stored in a refrigerator until further analysis.

2.3 Total phenolic and flavonoid content of BSC

The total phenolic content (TPC) was quantified using the Folin-Ciocalteu (FC) colorimetric method, as described by Singleton et al. [11]. This technique relies on the spectrophotometric measurement of the blue-colored complex formed from the reaction between phenolic compounds and the Folin-Ciocalteu reagent. A gallic acid stock solution (1000 mg/L) was used to generate a calibration curve. For analysis, 70 µL of the sample was combined with 300 µL of Folin-Ciocalteu reagent and 230 µL of 7.5% sodium carbonate, then incubated at room temperature for 90 minutes. Absorbance was recorded at 765 nm. All measurements were performed in triplicate, and results were expressed as milligrams of gallic acid equivalents per milliliter of condensate (mg GAE/mL).

Total flavonoid content (TFC) was quantified using a colorimetric assay based on the method by Lesjak et al. [12]. Briefly, 30 µL of the extract (1, 1.5, and 2 mg/mL) or quercetin standard (0.625–80.0 µg/mL) was combined with 6 µL of 10% aluminum chloride, 6 µL of 1 M sodium acetate, 90 µL of methanol, and 170 µL of distilled water. After a 30-minute incubation, absorbance was measured at 415 nm. All measurements were conducted in triplicate, and results were expressed either as milligrams of quercetin equivalents per gram of dry B*S*C (mg QE/g dry B*S*C) or as micrograms per milliliter of B*S*C (mg QE/mL B*S*C).

2.4 Qualitative analysis of phenolic compounds in BSC

The phenolic profiles of beech wood extract from direct steaming process was analysed. Identification of the phenolic compounds was performed using liquid chromatography (LC) with high-resolution mass spectrometry (HRMS) and tandem mass spectrometry (MS/MS). LC-HRMS/MS system was coupled with OrbiTrap Exploris 120 mass spectrometer. The experiment conditions for phenolic profile analysis followed the procedure previously described by Stojković et al. [13].

2.5 Particleboard production

Two series of one-layer particleboards were produced using a laboratory hot press to evaluate the effects of BSC on adhesive performance. The only difference between the two series was the formulation of the urea-formaldehyde (UF) adhesive: one series used pure UF resin, while the other used a UF adhesive in which BSC was added as a partial substitute for water (UF-BSC). In both cases, the concentration of UF resin was reduced to 50%, and in the BSC series, BSC replaced distilled water in the formulation. Ammonium chloride was added at 1% by weight (based on the solid content of the adhesive), and the total adhesive load was 10% relative to the oven-dry weight of the wood particles.

Adhesive application was carried out in a laboratory drum blender equipped with a pneumatic nozzle. The blended particles were manually formed into mats (500 × 440 mm) and pre-pressed. The final hot-pressing stage was conducted at 190 °C under a specific pressure of 2.0 N/mm^2 for 6 minutes. The target density of the particleboards was 700 kg/m^3, with a controlled thickness of 10 mm using distance bars.

2.6 Formaldehyde emission

In order to determine formaldehyde emission from prepared particleboards, the gas analysis was performed according to the standard test method EN ISO 12460–3: 2015 [14] by GreCon gas analyser (Fagus-GreCon Greten GmbH & Co. KG, Germany). Each sample series were tested in duplicate, using test pieces of 400 x 50 mm. Test pieces were placed in a preheated test chamber exposing the sample to heated air at 60°C, with a RH ≤3% and an air flow of 60 L h^{-1}. The air was continuously drawn from the chamber and passed through gas wash bottles, containing distilled water, which absorbed the released formaldehyde. At the end, the F concentration was determined photometrically based on the Hantzsch reaction. The F release was calculated from this concentration, the sampling time, and the exposed area of the test pieces and expressed as mg m^{-2} h^{-1}.

3. Results and discussion

3.1. Total phenolic and flavonoid content of BSC

Phenolic profile of BTC was determined by evaluation of total phenolic content (TPC) and total flavonoid content (TFC) (Table 1), as well as LC-MS analysis (Table 2). High total phenolic content (TPC) values, along with LC- MS analysis (Table 2), confirmed the presence of numerous phenolic constituents in BSC.

Table 1. Total phenolic content (TPC) and total flavonoid (TFC) content in BSC.

Sample	TPC (mg GAE/mL)	TFC (mg QE/mL)
BSC	1.62± 0.27	1.74± 0.57

*BSC – beech steaming condensate; GAE – galic acid equivalents; QE – quercetin equivalents.

Table 2. Identified phenolic compounds in BSC, using LC-MS.

Organic acids	**Benzoic acids**	**Flavonoids**
Glutaconic acid	Gallic acid hexoside	B type proanthocyanidin dimer
Aconitic acid	Gallic acid dihexoside	B type proanthocyanidin trimer
Citric acid	Hydroxybenzoic acid isomer 1	Catechin
Succinic acid	Syringic acid	Epicatechin
Isocitric acid	Syringic acid hexoside	Taxifolin 3-O-hexoside
Cinnamic acids	Methyl dihydroxybenzoate	Taxifolin 3-O-pentoside
p-Coumaric acid	Methylgallic acid	A type proanthocyanidin dimer
Ferulic acid	Dihydroxybenzoic acid isomer 2	Quercetin 3-O-hexoside
Lignans	Syringoyl leonuriside A	Quercetin 3-O-pentoside
Syringaresinol dihexoside	Hydroxy-methoxyphenyl-syringoyl hexoside	Taxifolin
Lyoniresinol hexoside	Benzoyl deoxypentoside	Quercetin 3-O-rhamnoside

Lyoniresinol pentoside	Hydroxybenzoic acid isomer 3	Luteolin
Syringaresinol hexoside	Syringoyl leonuriside A	Quercetin
		(Epi)catechin ethyldimer
		Dihydrokaempferol
		Dihydrokaempferol
		Quercetin 3-O-hexoside

The wood steaming process, driven by high temperatures, steam, and microbial activity, promotes the degradation of lignocellulosic structures, leading to hydrolysis and facilitates the migration of extractives to surfaces followed with the release of these compounds into the condensate [15]. This process also increases the acidity of the medium, which further facilitates the cleavage of covalent bonds. Over 50 compounds were identified, mainly of phenolic origin, including phenolic acids, flavonoids, and lignans, present in both aglycone and glycosylated (mainly hexoside) forms (Table 2). They can significantly affect the properties of wood-based composites, especially in relation to formaldehyde emissions from synthetic adhesives such as urea-formaldehyde (UF) resins. It has been also confirmed that water-soluble wood extractives, predominantly phenolic in nature, readily react with formaldehyde [16]. The type of wood and its anatomical characteristics play a crucial role. Softwoods, such as spruce (**Picea abies**) and pine (**Pinus sylvestris**), typically contain lower amounts of phenolic extractives compared to hardwoods, which often results in different formaldehyde emission profiles [17].

3.2. Particleboard production and impact on formaldehyde (F) emission

Two series of one-layer particleboards were prepared in laboratory conditions with defined characteristics (Table 3, Figure 1), using either pure UF resin or UF-BSC adhesive, to evaluate the effect of beech steaming condensate on formaldehyde emission.

Table 3. Particleboard characteristics.

Density	700 kg/m^3
Dimensions	0.5 x 0.44 x 0.01 m
Moisture content	8%
Adhesive content	10%
Mass of wet particleboard	1540.00 g
Mass of dry particleboard	1296.30 g

Figure 1. Particleboard production: a) carpet thickness before pressing; b) particleboard.

Wood-based panels bonded with UF adhesive are known for their subsequent emission of formaldehyde that may even last a longer period [18]. This formaldehyde emission became the subject of many national and international regulations and standards. There are several European standards that set the allowed FA emission limits for different types of panels, of which the EN 312 (2010) standard [19] refers to the particleboards. Also, the EN 13986 (2004) standard [20] standard defines the emission limits for the panels used for construction purposes [21].

The results of gas analysis (Table 4) indicate that replacing deionized water with liquid beech condensate during adhesive preparation effectively reduces formaldehyde emissions. This is in accordance with previous study of influence of incorporating BSC into the UF resin formulation on the curing behavior and kinetics of the adhesive system [10] suggesting an acceleration of the curing process. This enhanced reactivity is likely due to the interaction between phenolic compounds in BSC and free formaldehyde. Comparable findings by Xu et al. [22] demonstrated that the inclusion of tannin or glyoxalated tannin in UF systems reduced the curing temperature and accelerated the reaction, while also lowering formaldehyde emissions and enhancing adhesive performance. One of the key mechanisms through which wood extractives influence formaldehyde emission is their chemical reactivity. Phenolic extractives, abundant in hardwood species contain hydroxyl groups capable of binding free formaldehyde via nucleophilic addition, forming stable methylene bridges or hemiacetals. This mechanism can reduce the amount of free formaldehyde in the final product, thus lowering the overall emission levels [23,24].

Table 4. Formaldehyde emission of particleboards

Particleboard sample	UF ($mg\ m^{-2}\ h^{-1}$)	UF-BSC ($mg\ m^{-2}\ h^{-1}$)
F	12.8333± 2.0872	9.2500± 2.3477

Ayrilmis et al. [7-9] investigated the use of wood-drying condensates—typically considered industrial waste—as functional additives and formaldehyde-reducing agents in UF and MUF resins. These condensates, obtained during high-frequency/vacuum drying of oak, beech, and walnut, replaced 5 wt% of deionized water in the resin formulations. The modified resins maintained technical properties within commercial standards. Both particleboards (PB) and medium-density fiberboards (MDF) produced with these resins met EN 12765 requirements, despite a slight reduction in bond strength for MDF. Notably, the modified resins showed significantly lower formaldehyde emissions, attributed to phenolic and acidic

components in the condensates that chemically bind or adsorb free formaldehyde—findings consistent with the present study.

3.3. ***Environmental and industrial relevance***

Utilizing condensates as functional additives in resin synthesis offers a dual benefit:

1. Waste valorization — transforming a polluting byproduct into a valuable input.
2. Sustainability enhancement — reducing indoor air pollutants from wood-based products, aligning with LEED® green building certification standards [25].

This approach supports a circular economy framework in the wood industry and aligns with global efforts to minimize formaldehyde exposure in indoor environments.

4. Conclusion

This study investigated the potential use of condensate produced during beech wood steaming as a substitute for deionized water in the formulation of urea-formaldehyde (UF) adhesive intended for wood-based panel production. The results demonstrate that liquid beech condensate decreases formaldehyde emission when used as a substitute for deionized water during adhesive preparation. This finding presents an opportunity to integrate two industrial processes — beech wood steaming and wood-based panel (WBP) production — by utilizing a by-product of one as a raw material in the other. Employing beech condensate in UF resin formulation offers both environmental and economic advantages. It provides an effective solution for managing the large volumes of condensate generated during wood steaming, converting potential wastewater into a valuable input for WBP production. This approach eliminates the need for additional post-treatment, as the condensate is fully incorporated into panel manufacturing and permanently embedded within the final product. Ultimately, this strategy supports sustainability and resource efficiency by promoting circular utilization within the wood industry.

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Investment in Modern and Innovative Technology in Sawmilling

Selver Smajić

Faculty of Forestry and Wood Technology, Zagreb, Croatia

E-mail: selver1401@gmail.com

Abstract. If we observe the latest trends in the field of technique and technology, production development is one of the most important factors of any business environment. In order for business success to be possible and achievable in reality, it is necessary to offer the market something new, which has not been or rarely been seen so far. The basic and main goal of every innovation and innovation process should be better business success. The high demands of customers today are reflected precisely in the necessary innovation, ability to act fast and concreteness. These unavoidable theses are especially present in production processes related to the sawmilling, solid board and furniture production. So if we want to be successful, competitive and actively present on the market, it is necessary to invest in production technology and keep up with the competition. In this paper detailed information are shown, about forest fund of Bosnia and Herzegovina, current sawmill capacities, as well as technological possibilities of sawmills in Bosnia and Herzegovina. Also potential improvements to the current situation with some strategic conclusions are also provided.

1. Introduction

Bosnia and Herzegovina has a very long tradition in wood processing. The great development of the wood industry, primarily through sawmill wood processing, was contributed by the coverage of the territory with quality and various forests as well as the traditional way of entrepreneurship. In general, we can say that sawmill production from its very beginnings in the fifties of the last century is based on the production of timber. The production of furniture, which a little later also begins to develop, is closely linked to sawmill processing as the main source of raw materials. The forest fund in Bosnia and Herzegovina is estimated at about 291 million m3. Usually conifers are about 108 million m3, and deciduous trees about 183 million m3. The annual volume increase is about 7.92 million m3, of which 2.59 million m3 falls on quadruple waste, and 4.65 million m3 on deciduous trees. The possible annual volume of felling is 7.23 million m3, which is about 0.70 million m3 less than the annual natural increase. One of the biggest reasons for this deficit in the volume of logging is that a large part of the area (about 100,000 ha.) Is covered with mines from the previous war. The main forest raw materials represented in Bosnia and Herzegovina are: fir, spruce, white and black pine, beech, various species of oak, as well as some noble deciduous species such as: maple, elm, ash, and some fruit trees (pear, apple and cherry). Only forest management and use in Bosnia and Herzegovina has gone through certain stages of development. The path from simple production, meeting the needs for male, medium and multi-complex production, to the way of industrial production and wood processing. The scope of activities, the manner of use and the economic importance of forest products were reflected in relation to people according to the measures for the preservation and protection of forests and exploitation facilities.

2. Main products in sawmills of Bosnia and Herzegovina

Sawmills in Bosnia and Herzegovina are mainly oriented to work for the needs of final wood products, either as part of other final plants, which are not in the system with the sawmill or for wood processing as a finished export product. The product range of primary wood processing, i.e. primary sawmills, are sawmills: uncut sawmills, primarily loose, semi-loose, log and trimmed sawmills, and other types of sawmill products are produced such as sleepers, beams, billets, slats, etc. poorer quality, so-called finishing, are also

part of the range of primary wood processing, intended for processing in the finishing sawmill. Dedicated wood elements and springs are made in the finishing sawmill from primary sawmills. Sawmill products, classic or in the form of dedicated wood elements, are usually used for further processing into final products such as furniture, wooden floors, wood products for construction, wood accessories and various other wood products. Hardwood sawmill products are usually made from oak, beech, ash and some other species, such as maple, acacia and hornbeam. Uncut and semi-cut sawmills, solitary, semi-loose, finishing sawdust and various types of wooden elements and springs are most often made (Figure 1).

Figure 1. The most common products in sawmilling
*(*A – sawn wood elements, B – half-edged sawn boards, C – un-edged sawn boards*)*

Thresholds and shutters are made in slightly smaller quantities. Soft hardwood products include products made of linden, poplar, willow and alder. As a rule, unfinished sawdust and logs and wooden elements are made of soft hardwood. Planks and slats are exceptionally made of poplar and willow, most often for making pallets. Exceptionally, betting can be made from all types of soft leaves. The coniferous sawmill products are those made from fir and spruce logs, and in smaller quantities from the logs of common and black pine and larch. Softwood logs are usually processed by the technique of prism and sawing the whole. Unlike hardwoods, sawdust is most often made in a truncated shape. In addition to elements for construction joinery and furniture, fir and spruce are used to make construction materials, beams, billets and battens. Sawdust from various types of fruit trees is produced in very small, almost negligible quantities.

3. Technological possibilities of sawmilling in Bosnia and Herzegovina

There are many factors that have influenced the technology and changes in Bosnian-Herzegovinian sawmilling in recent history. The most important factor is the change in the quality of logs, especially the decline in their quality and diameter. The next, no less important factor is the development of domestic and world wood finishing as well as the general development of machinery and equipment. Hardwood logs in classic sawmills until fifty years ago were processed mainly on sawmills. Due to the high, at that time common quality of logs, the produced sawdust had a satisfactory quality. On sawmills, logs were normally processed exclusively according to the principles of maximum quantitative yield (Figure 2). The growing demand for better quality sawmills, with a simultaneous decline in the quality of logs, has contributed to the introduction of band saws in hardwood sawmills, as well as conifers. Individual sawing of logs with band saws contributed to the increase in the production of better quality sawdust. Technological changes in BiH sawmilling are aimed at achieving maximum value yield as a result of quantitative and qualitative yield, and thus towards increasing the effect of processing in the intended processing of logs with regard to the current classic sawmill processing. Previously, the classic sawmill technology was used to make sawmill products according to certain quality standards, and as a rule they were intended for an unknown market and an unknown customer. Today, dedicated sawmill technology is used to make specified sawmill products for known final products.

According to the technological basis, dedicated sawmills in Bosnia and Herzegovina can be classified into two groups:

- sawmills that are not directly related to certain final industry plants,
- sawmills that are directly related to certain plants of the final industry.

Figure 2. Traditional sawmilling machine

The main specificity of sawmills that are not directly in the system with the final industry is that they make solitary products for the market from quality primary sawmills as a finished product. All the others, bad, the so-called sawdust for finishing and the part of the sawn material that remains during the production of the logs, are processed into sawn elements for various final wood processing plants. The part of the sawn material that does not correspond in dimensions and quality to the production of elements intended for final products, eg. furniture, is used for the production of springs. Sawmills that are directly included in a system with some wood finishing plant have slightly different characteristics. When processing logs, uncut sawdust, i.e. loose and sawn elements, can be produced. If the finishing plants that are in the sawmill system do not need that sawn timber, the sawmills also make solitary confinement for the market. Loose ones are made of higher quality primary sawdust and in quantities that do not impair the needs of final processing. If the final production has the needs for the entire material, then all sawdust is purposefully processed into sawn elements. In general, the wood industry of Bosnia and Herzegovina is characterized by a large number of smaller companies, and very few large producers. The problem of overcapacity of the sawmill industry, which is still three times higher than the allowed felling rate in our forests, is particularly pronounced. The situation in a large number of plants for primary wood processing is quite bad. The equipment is thirty years old, and somewhere forty or more years old, with work often in two shifts, technically worn out. Technologically backward equipment cannot be used to process logs, from which high-quality sawdust would be obtained (e.g. problems with sawing accuracy, sawdust surface quality, etc.). By processing it is not possible to achieve optimal quantitative and qualitative yield of logs, to achieve the processing of the required quantities of logs, to increase labour productivity, etc. Most finishing sawmills are in a similar condition as the primary sawmills. A number of primary and finishing sawmills are equipped with modern equipment for cutting sawdust with computer-aided optimization, imported technological operations, as well as a completely closed production cycle between primary and finishing (secondary) processing (Figure. 3).

Figure 3. Modern sawmill production with automated sawmill transport line and computer-controlled central control console for primary sawing

There are a large number of sawmills that are still used for primary sawing. It is generally known from the past that band saws have a number of advantages over hardwood saws, which are related to the individual way of sawing, greater possibilities of different sawing techniques, etc. Despite their advantages, they are still underused. Numerous sawmills have little or no solution for sawdust residue, i.e. for sawdust, bark, crusts and edges. Mostly these residues are used for the production of thermal energy or sold to the population for heating. This is why sawmills often have major problems and costs for disposing of all leftovers in late spring, summer and early autumn. It should be mentioned that sawmills are increasingly investing in plants for the production of briquettes, pellets and charcoal.

4. Improvement of the current situation and directions of action

The future development of industrial wood processing in Bosnia and Herzegovina has been the subject of various studies in recent years. Some studies have also touched on the sawmill industry. The relationship between transport costs and the value of sawmill logs economically requires the approximation of certain sawmill capacities to the forest area, especially where the wood raw material is of lower quality and lower value. This should encourage smaller sawmill capacities to be started closer to the wood raw material, i.e. sawmills of those capacities that will correspond to the available raw material in terms of type, quality, diameter, quantity, etc. Spatial approximation of primary sawmills of certain capacities to wood raw material will be necessary in order to enable profitable processing and reduce transport costs to consumers in relation to the costs of transport of primary sawmills. Due to the additional profit, it is to be expected that in addition to the primary sawmill plants, steaming and drying capacities will often be started, so that in the end it will be possible to deliver sawmills with the percentage of moisture required for the final product. Reduction of costs in wood processing should be achieved by processing part of the primary sawmills into sawn wood elements, while the rest as sawdust, small residues, etc. remain at the location of the sawmill, and they amount to 40% and more. The production of primary sawdust is the basis for the development of wood processing into products with a higher degree of finalization. Certain assortments of primary products in lower quality and usability have a poor chance of successful sales without a certain degree of refinement. Primary sawdust will be processed in the finishing sawmill in fresh condition or dried to the final moisture required for the final wood product. Finishing sawmills of smaller capacity, which are not in the sawmill system, will most often produce rough sawn elements in dried or fresh condition and with the desired water content from primary sawmills. They will be organized as finishing sawmills and should be in cooperation with the plants for final wood processing. Finishing sawmills of larger capacities, which will be in the system of primary sawmills, as well as those that will be technologically, organizationally or proprietarily separated from primary sawmills should, as a rule, produce rough, semi-finished, and exceptionally finished elements of desired dryness. When it comes to newly equipped, modern or renovated sawmills in terms of technological equipment and modernization and computer support of installed machines and lines, increasing importance will be given to the factors of improving sawmill production:

- high degree of automation and application of computer technology,
- improving the quality of sawing or processing of sawdust,
- increasing the yield of sawmill raw material (sawing accuracy, sawdust width, appropriate adjustment of sawing logs, etc.),
- increasing the capacity of machines,
- longer service life of machines, especially longer time of use of saw blades by carrying out the process of sterilization and making tooth tips from quality hard materials,
- greater safety at work, better working conditions for workers, solving the problem of noise and wood dust or care for the environment in the broadest sense, etc.

In the sawmill processing of hardwoods, the comparative advantages of band saws will be used more, and most of all the individual approach to sawing logs. Already today, band saws are equipped with computers and software to determine the position of the sawdust with respect to the given thickness of sawdust. For less valuable raw materials, such as logs of smaller diameter, modernized versions of the sawmill with movable saw blade stacks are used. For such raw material, multiple and multi-blade circular saws and logs will be used more and more often, with which parts of thinner logs will be processed into certain sawmill

products of precisely defined dimensions and purposes. Band saws are still of great importance in the processing of conifers.
Certain comparative advantages of the sawmill when sawing conifers also continue to be used in part. Although for the processing of one part of this type of sawmill raw material, there is a possibility of processing with multi-blade band and circular saws with logs or chippers. In general, it will take a long time to accept this way of sawing and this technology in our area. Using computer-aided lines, today the production of sawn elements in newly equipped finishing sawmills is such that the sawmills are usually first cut lengthwise into work pieces of given widths, and then these work pieces are transversely cut to certain lengths according to the given specification.
This method of production enables obtaining a larger amount of longer elements, which are most often sought after and have the greatest value. Part of the finishing sawmills continues to process sawmills transversely by the longitudinal sawing method, regardless of the available technology and production concept. With the introduction of new technologies with computer support, the need for experts has increased, which will be reflected in the improvement of the quality of their education. In this regard, new education plans and programs have been created, both in secondary vocational schools for various professional occupations and at the faculties for managerial staff.

5. Conclusions

The strategic commitment of the state and the wood profession should be to change and improve the structure of exports of wood products in favour of products with a higher degree of finalization. Modern sawmill processing should be based on dedicated technology, processing of input raw materials, sawmill logs and long round wood, mostly in full, into sawn elements intended for final finalization into certain finished products for a known customer. Such sawn elements must meet the needs of the final products industry in terms of their dimensions, wood quality, processing quality, water content in the wood, accuracy of delivery and, possibly, other special requirements.
Modern sawmill technology requires modern, efficient equipment in primary and secondary sawmill machines as well as other appropriate devices, with the application of computer technology.

Special emphasis is placed on the need to use, as primary sawmill machines, modern band saws, with the possibility of sawing in parallel with the log sheath and at least partially computerized lines for processing primary sawmills into dedicated elements for different needs in the final furniture industry, construction joinery, all different floor elements, wall coverings and numerous other products.

For many economic and organizational reasons, it is useful for modern dedicated sawmills to produce sawn work pieces for a number of final plants. Increasing the productivity of sawmill production is necessary, but to some optimal level

Sawmill wood processing should primarily be in the service of high-value products of our final industry such as furniture production. In general, the final products industry must also fight for such a development strategy. Otherwise, the sawmills, especially those in their most primitive technical - technological edition, will advocate only their profitable interests: produce primary sawmills, possibly with the most necessary level of finishing, and place them on foreign markets. Both primary and final wood processing should lead to a joint economic, technological and technical discussion on this problem, in order to make better and more successful use of the common raw material, which is less and less on the market.

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Artificial wood-based materials for prefabricated houses

Emeritus Prof. Dr. Salah-Eldien Omer[1] and Assoc. Prof. Dr. Minka Cehic[2]

[1], Antuna Vramca 17, 10000 Zagreb, Croatia
[2]University of Bihac, Faculty of Technical Engineering Bihac,Bosnia and Herzegovina

*E-mail: minka.cehic@unbi.ba

Abstract. This paper presents new information about the basic materials recommended for use in modern prefabricated houses. It discusses various wood-based materials suitable for such constructions. The focus is primarily on structural wood materials, exterior wood siding and cladding, as well as interior finishing materials. Finally, the paper provides recommendations for the application of these materials.

1. Introduction

Wood and wood-based materials are the fundamental building blocks of nearly every prefabricated wooden building. They are considered excellent construction materials by most producers, aligning well with all concepts of sustainable construction. These materials are ecological, energy-efficient, and offer excellent physical and mechanical properties. They provide good sound insulation, can withstand high fire loads, and adapt well to heavy pressure loads.

Wood-based materials help maintain a pleasant indoor climate throughout all seasons, regulate humidity, and function as a natural biological filter. They are warm to the touch and have a positive influence on overall well-being.

Construction using wood and wood-based materials, especially in regions where it is a traditional practice, promotes a high-quality lifestyle. Modern wood-based materials, produced using advanced adhesives, offer improved flexibility and performance of elements used in prefabricated wooden buildings. New types of engineered wood boards have been developed to meet the specific characteristics required for construction, particularly in the context of prefabricated housing.

The advantages and disadvantages of building with wood and wood-based materials are illustrated in the following table (Table 1).

Table 1. The Advantages and Disadvantages of Building with Wood and Wood-Based Materials.

PROS	CONS
Readily accessible	Quick structural depreciation
Less expensive	High maintenance cost
Versatile	Susceptible to moisture and mold
Lightweight and easy to transport	Vulnerable to fire
Easily machinable	Less effective as a soundproofing material
Biodegradable	Prone to noisy, creaking floors

Wood construction using modern wood-based materials offers superior insulation compared to other building materials. Wood has 15 times lower thermal transmittance than concrete and 4 times lower than brick. Additional key factors contributing to energy efficiency include thicker insulation of external walls, the appropriate selection of insulation materials that provide optimal thermal transmittance and thermal lag. This helps prevent overheating during warmer months and reduces heat loss during winter.

A well-planned installation of energy-efficient building joinery, good air tightness, controlled ventilation with heat recovery, and the use of renewable energy sources all contribute significantly to creating a sustainable home.

Although wood and wood-based materials are combustible, they can withstand a greater fire load than concrete or steel. When glued timber burns, a thin charred layer forms on the surface, which limits oxygen access to the interior and slows the spread of the fire. Artificial wood-based materials have significantly better fire-resistant properties, especially when enhanced with high-quality adhesives and specialized chemical additives now commonly used in their production [1].

Innovative prefabricated materials are transforming the construction landscape with their exceptional benefits, making them a preferred choice for modern building projects.

Environmental Responsibility:
The use of materials such as recycled steel, reclaimed wood, and eco-friendly composites helps reduce waste and promotes the use of renewable resources. These sustainable choices are guiding the industry toward more environmentally responsible and future-friendly construction practices.

Productivity:
Building off-site in controlled environments helps speed up construction, minimize on-site disruptions, and reduce labor costs, leading to quicker and more efficient project completion.

Quality Control:
Factory-produced components undergo rigorous quality checks to ensure precision, consistency, and durability. This guarantees that the final structures not only meet but often exceed industry standards.

Cost-Effectiveness:
Prefabrication significantly shortens construction timelines, reduces labor needs, and minimizes material waste—resulting in substantial cost savings without compromising quality.

Flexibility in Design:
Innovative materials such as carbon fiber-reinforced polymers and 3D-printed components allow architects to explore unique and creative designs, enhancing the aesthetic appeal of modern structures.

Improved Performance:
Smart materials like self-healing concrete and adaptive insulation increase the durability and efficiency of buildings by responding to environmental changes and reducing maintenance requirements.

Advanced prefabricated building materials are transforming the construction industry through sustainability, efficiency, and versatility—offering a smarter, more eco-friendly approach to building [2].

Structural Wood-Based Materials
We begin with the boards and elements commonly used in prefabricated wooden houses—primarily for framing, walls, floors, and roofs. With the growing focus on rationalizing the use of wood as a raw material, a wide range of engineered wood products has been developed and continuously improved for specific applications in construction.

One of the earliest and most significant of these products is laminated veneer lumber (LVL), which is known for its strength and dimensional stability (see Figure 1).

Laminated Veneer Lumber (LVL)
They are manufactured in a process similar to plywood, where rotary-peeled wood veneers (typically from pine or fir) are dried and then laminated together using adhesives and resins under heat and high pressure. In LVL, all the wood grain runs in the same direction, giving it excellent stiffness and dimensional stability.

Due to its high tensile strength, LVL can support substantial weight along its length without sagging. This strength also enables it to span long distances without requiring intermediate supports. LVL offers high design values—not only in bending but also in stiffness and shear strength.

Where is LVL most commonly used?
In building construction, LVL is primarily used for beams and joists. Its strength makes it ideal for door and window headers, stair stringers, and other structural beams. Although designed for structural applications, its surface finish is of low architectural quality. In larger-scale construction, LVL is used in applications where a high-strength, lightweight member is needed.

Many companies now offer engineered wood products with varying performance specifications. Manufacturers often apply sealants to protect LVLs from moisture damage. They do not require special fasteners and are installed just as easily as conventional lumber.

LVL has no knots or defects to cut out, reducing jobsite waste. Since LVLs use rotary-peeled veneer rather than solid-sawn timber, this process saves a significant number of trees and uses wood resources more efficiently—even from logs that might otherwise be considered low-quality [3].

Cross-Laminated Timber (CLT)

The second structural wood-based material—both modern and engineered—is Cross-Laminated Timber (CLT). This product is a subcategory of engineered wood panels, made by gluing together at least three layers of solid-sawn lumber, each oriented at right angles to the one below. It is similar in concept to plywood but features significantly thicker laminations (lamellae).

The grain of each board layer is typically rotated 90 degrees from adjacent layers and glued along the wide faces of the boards, often in a symmetric configuration—meaning the outer layers are aligned in the same direction. While CLT commonly has an odd number of layers, even-layer configurations also exist, arranged symmetrically.

Unlike standard timber, which is anisotropic (having varying properties depending on the direction of applied force), CLT panels achieve enhanced structural rigidity in both directions due to their cross-laminated structure.

CLT vs. Glulam:

CLT is distinct from glued laminated timber (glulam), in which all laminations run in the same direction. (See Figure2)

Advantages of CLT as a Building Material:

- Design Flexibility
- Environmentally Friendly (includes carbon capture)
- Excellent Thermal Insulation
- Lightweight
- High In-Plane and Out-of-Plane Strength and Stiffness
- Fire Resistance – Classified as REI 90, meaning it retains its structural capacity and integrity for at least 90 minutes in the event of a fire

Figure 1. A New Type of Laminated Veneer Lumber (LVL).

Figure 2. Cross-Laminated Timber (CLT) Using New Types of Adhesives.

Oriented Strand Board (OSB)

The third type of board selected for consideration in this paper is Oriented Strand Board (OSB). OSB is an engineered wood product made by bonding wood strands together with industrial-grade adhesives. Additionally, a water-resistant wax coating is applied to the strands for extra protection. The edges of each OSB panel are sealed to further enhance its resistance to water.

It's important to distinguish between "exterior use" and products designed for "use as exterior sheathing." OSB is not suitable for unprotected outdoor use, but it is well-suited for exterior sheathing on walls and roofs.

Plywood

The fourth type of board discussed in this paper is the new type of plywood, which is used widely as a building material. Plywood is one of the most recognized engineered wood-based panel products in construction. It consists of resin and wood fiber sheets bound together to form a composite material sold in panel form. A standard plywood panel typically has face veneers of higher quality than the core veneers. The function of the core layers is to increase the separation between the outer layers, where bending stresses are highest, thus improving the resistance to bending forces.

Plywood panels are fabricated from multiple layers of softwood veneer glued together, with the grain direction of each layer perpendicular to the adjacent layers. These cross-laminated sheets of wood veneers are fastened together using a waterproof phenol-formaldehyde resin adhesive, then cured under heat and pressure. Manufacturers produce a range of plywood products for structural and non-structural uses, suitable for both wet and dry conditions. These include sub-flooring, single-layer flooring, wall and roof sheathing, structural insulated panels, webs of wood I-joists, and concrete formwork.

As exterior wall and roof sheathing, plywood can provide resistance to lateral forces, such as wind and earthquake loads, and forms an integral component of the building envelope. It can also be used as both structural sheathing and finish cladding. For exterior cladding applications, specialty plywood products are available in various patterns and textures, combining the natural characteristics of wood with the strength and rigidity required for these applications [5].

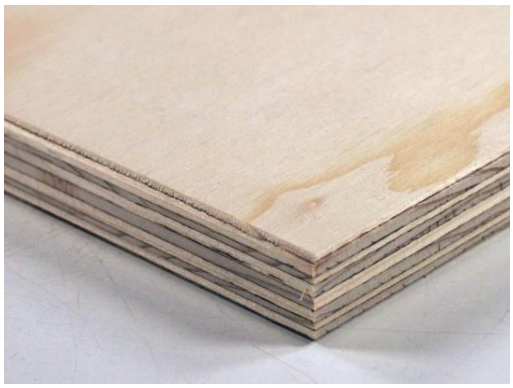

Figure 3. Multilayer Plywood for Various Applications.

2. Exterior wood-based materials for siding and cladding

Natural wood-based materials can be used in various applications due to their beauty, versatility, and unique qualities, making wood an unrivalled building material. As both an interior and exterior design element, wood adds warmth and a welcoming touch to any structure. The industrial processes used in producing wood-based materials have led to the development of artificial wood products tailored for different purposes, particularly in the construction of wood prefabricated houses.

The main goal in producing these materials is to meet the specific characteristics required for each product. Materials used for siding and cladding on wood prefabricated houses are often produced in specialized processes based on custom orders. These products are typically manufactured according to established standards and recommendations.

With advancements in technology and the rise of sustainable architecture, wood is regaining its status as a preferred construction material. As a renewable and eco-friendly material with a low environmental impact, wood-based materials are ideal for creating healthy and sustainable living environments. There is no better alternative for building sustainable structures than wood and its engineered variants.

Choosing the right exterior cladding (see Picture No. 5) for your home is a crucial decision. In addition to seeking a visually appealing finish, you need a material that is durable, solid, dimensionally stable, and resistant to various weather conditions. The numerous advantages of thermally modified wood-based

materials make them perfect for outdoor applications such as timber cladding and decking. With an ideal balance of aesthetics and functionality, it's no surprise that thermally modified wood has become one of the favoured building materials for architects around the world [6].

Figure 4. Exterior Wood Siding - Special Production.

Figure 5. Exterior Wood Cladding for Multi-Floor Buildings.

There are countless inspiring ways to clad your building in natural wood. If you're considering wood-based materials for your exterior finish, it's essential to explore the latest trends in wood products designed for this purpose. Many architects and builders prefer long cladding boards for their sleek, continuous look, while short lengths offer their own unique charm.

Thanks to innovative installation methods, the process of cladding your house has become both easy and efficient, often resulting in a smooth, screw-less finish. The result is a creative and unique exterior that enhances the building's character (see Figure 6).

For building envelopes, high-quality cladding products can be highly durable, weatherproof, and require little to no maintenance, even in the most demanding climatic conditions.

To meet the demands of durable and sustainable building materials, the industry has developed thermally modified wood (also known as Thermo Wood). This innovation originated in Finland in the 1990s, where thermal modification technology was first established. Essentially, it involves a process where wood is heated to significantly increase its durability and performance.

Thermal modification enhances several properties of wood, making it a highly sought-after material. It improves dimensional stability, meaning the wood no longer reacts to changes in humidity. This makes it ideal for exterior applications such as cladding, decking, saunas, and under-floor heating. Modified wood absorbs less moisture than untreated wood, reducing the risk of mildew and mold while withstanding heat more effectively. Despite these improvements, thermally modified wood retains its natural beauty, exhibiting a deep and even tone.

The process follows a consistent method: the wood is heated to a temperature of up to 215°C over a period of 48 hours. This process reduces the equilibrium moisture content of the wood, after which it is cooled. Notably, no chemicals are used in this process—only heat and steam. As a result, softwoods undergo a transformation, improving their durability to the equivalent of H3 level, which corresponds to a 30-year expected service life for vertical applications such as cladding.

An added benefit of thermal modification is an improvement in thermal insulation properties by approximately 20%, further enhancing its efficiency in energy use. All of this is achieved without the use of preservatives or chemicals, making thermally modified wood an ideal choice for eco-friendly applications, particularly in decking, cladding, and weatherboard applications, where "healthy" building materials are desired [6].

3. Interior finishing wood based material

Wood-based material manufacturers are increasingly combining decor elements from furniture, interior design, and flooring to create entirely new, innovative products. The wood-based panels offered in most markets today are primarily three-layer boards, with the outer layers usually consisting of veneer.

Veneer refers to thin slices of wood, and sometimes bark, which are typically glued onto core panels made of materials like wood, particle board, or medium-density fiberboard (MDF). These panels are then

used to create flat surfaces such as doors, countertops, cabinet panels, parquet floors, and furniture components.

Such products are often designed for specific uses in wood prefabricated houses, tailored according to the requirements of the final user or the preferences of architects.

Figure 6. Structural Three-Layer New Parquet.

An important component of the requested artificial parquet is the top layer, which is often requested to be highly effective and visually impressive. This top layer is usually made from high-quality veneer, often sourced from exotic tree species with high density, which requires the use of modern, high-quality adhesives. The middle layer also needs to be selected from high-quality materials to ensure the recommended characteristics of the parquet are met.

For interior finishing materials, Medium-Density Fiberboard (MDF) is often used, primarily in the production of cabinets, doors, and interior trims. MDF is an engineered wood product made from pulverized wood fibers, resins, and wax, pressed into sheets under heat and pressure. Due to its heavy, strong construction, it can be used in many applications similar to high-grade plywood. The surface of MDF is very smooth, making it excellent for use in painted or veneered cabinetry and furniture. MDF is often specified where extra fire resistance is required.

4. Conclusions

- The production of wood-based materials continues to evolve, creating new materials that satisfy the needs of wood prefabricated houses.
- Wood construction using modern wood-based materials enables better insulation, especially with new glues and additives, compared to other building materials.
- Structural wood-based materials, both modern and artificial, are typically produced with specific glues (resins) and additives, which ensure the materials possess the required characteristics for their intended use.
- One of the first products of this kind is laminated veneer lumber (LVL), which is strong and dimensionally stable. Due to its high tensile strength, LVL can support considerable weight along its length without sagging.
- The second structural wood-based material, Cross-Laminated Timber (CLT), is a subcategory of engineered wood panels made by gluing together at least three layers of solid-sawn lumber at right angles to each other. This makes CLT ideal for use in wood prefabricated houses. It is similar to plywood but with thicker laminations, which enhances its strength.
- Plywood is one of the most widely recognized, multi-purpose engineered wood-based products used in global construction projects. The core layers of plywood increase the separation between the outer layers, where bending stresses are highest, thus improving resistance to bending forces. Manufacturers produce a range of plywood products suitable for both structural and non-structural uses, such as sub-flooring, flooring, wall sheathing, roof sheathing, structural insulated panels, and concrete formwork.

- Wood-based panels currently available on the market as interior finishing materials are typically three-layer boards, such as parquet with three classic layers. Additionally, MDF is often used for interior finishes like cabinets, doors, and interior trims. It can be cut and shaped with ordinary woodworking tools, making it versatile for various applications.

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Creation of a Virtual Prototype from Recycled Furniture

Emir Japić and Budimir Mijović

University of Bihac, Faculty of Technical Engineering Bihac, Bosnia and Herzegovina

E-mail: budimir.mijovic@unbi.ba

Abstract Wooden furniture represents an important part of our daily lives. However, when it comes to replacement or damage, many pieces end up in landfills, contributing to serious environmental issues. Recycling wooden furniture is not only an environmentally friendly solution but also an opportunity to reduce waste and reuse valuable resources. Recycled products offer a practical way to repurpose materials, decreasing waste volume and reducing the need for raw material exploitation. The green industry involves the application of innovative technologies and sustainable methods in production processes, promoting energy efficiency, reducing carbon dioxide emissions, and preserving the environment. This research not only emphasizes the importance of responsible resource management but also highlights the economic and social benefits of transitioning to a circular economy and the development of green technologies.

1. Introduction

The recycling of wooden furniture is becoming a key component of sustainable development in the furniture industry, given the global concern for waste reduction. Specifically, the wood furniture industry utilizes recycling as a mechanism to reduce the consumption of natural resources while simultaneously contributing to the reduction of carbon dioxide emissions. An example of such an item, for instance, a chair, represents a typical case of an older furniture piece made from solid wood. The chair's construction is simple yet sturdy, featuring classic decorative details on the legs and backrest [1,2].

The seat and backrest are upholstered with fabric that shows signs of wear and aging, while the wooden frame is coated with a layer of white paint, which is peeling off in certain areas. Although at first glance it may appear to be a piece of furniture destined for disposal, such chairs contain a significant amount of wood mass suitable for recycling [3,4].

The aim of this research paper is to present the process of recycling old chairs through their disassembly and the reuse of the recovered wooden material. Instead of ending up as waste, the wooden parts of the chairs will be shredded and processed into raw particleboards. These boards will then be treated by applying a laminate foil, edge-banded for edge protection, and used in the production of a new functional furniture item – a wardrobe [5,6].

This process serves multiple purposes: on one hand, it contributes to waste reduction and promotes a circular economy, while on the other, it provides an economically and functionally viable method for creating a new product. The research will present all key steps – from material preparation and particleboard production to final processing and assembly of the wardrobe – with a particular focus on sustainability and the reuse of wood materials [7].

2. Materijal and Metods

The recycling of wooden furniture also contributes to the reduction of carbon dioxide (CO_2) emissions. The production of furniture from recycled materials requires less energy compared to the production from new raw materials. For example, recycling wood reduces the need for transportation and processing of fresh resources, which in turn lowers CO_2 emissions. Studies show that recycling wooden furniture can reduce CO_2 emissions by approximately 50% compared to traditional production methods (Figure 1).

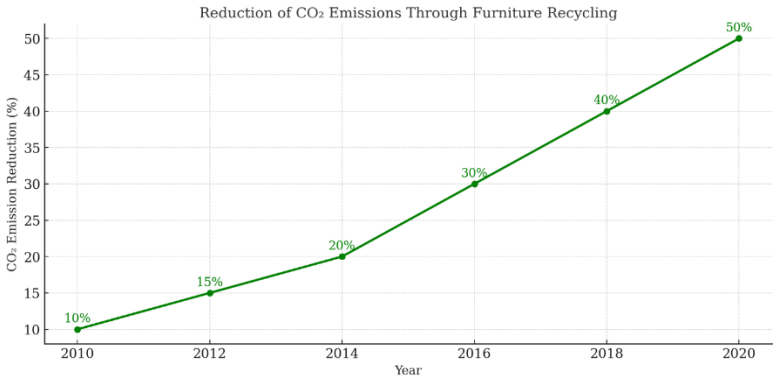

Figure 1. Reduction of CO_2 Emissions Through Recycling.

The horizontal bar chart illustrates the results of wooden furniture recycling expressed in percentages across five key aspects: quality improvement, resource savings, energy savings, CO_2 emission reduction, and waste reduction.

Each of these factors has a significant impact on the ecological, economic, and functional value of the recycling process. Quality improvement (55%) represents the highest share and refers to the enhancement of product quality after recycling, indicating improved functionality and aesthetic value. CO_2 emission reduction (50%) highlights how the recycling process significantly contributes to lowering carbon dioxide emissions, directly reducing the carbon footprint of production.

Waste reduction (45%) reflects the decreased amount of material ending up in landfills through recycling, thus supporting environmental preservation. Energy savings (40%) show that the recycling process consumes less energy compared to the production of new materials, offering additional ecological and economic benefits. Resource savings (35%) refer to the efficient use of natural resources, reducing the need for extracting new raw materials.

The chart clearly demonstrates that the recycling process not only contributes to environmental protection but also improves product quality, reduces costs, and increases energy efficiency. These methods represent a key step toward a circular economy and a more sustainable society (Figure 2).

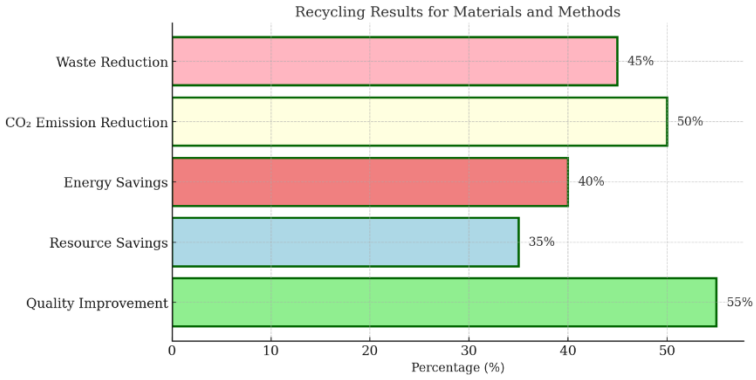

Figure 2. Recycling Results by Materials and Methods.

The process of recycling wooden furniture involves various materials derived from old furniture. The most commonly used materials include: Solid wood, originating from trees such as oak, beech, maple, pine, and other types of hardwood and softwood.

This material is most frequently used in old furniture and is suitable for recycling due to its durability and ability to be processed into new furniture pieces.Composite wood materials or composites, such as particleboard, medium-density fiberboard (MDF), and high-density fiberboard (HDF), which are often used in mass-produced furniture.

These materials are commonly recycled, although they may contain binders and adhesives that can complicate the recycling process. Metals, such as steel and aluminum parts used in furniture frames and mechanisms (e.g., chair legs, drawer frames).

These materials can be easily separated and recycled. Textiles, leather, and plastics – old furniture often includes textile, leather, or plastic components (e.g., upholstery on sofas and chairs). These materials can be recycled or reused in the production of new products. Glass – some furniture pieces, such as glass tables or cabinets, include glass elements that can also be reused or recycled.

The diagram illustrates the share of solid wood furniture in the total recycling process. Approximately 65% of recycled materials come from solid wood furniture, while the remaining 35% consists of other materials such as plastic, metal, foam, and fabric (Figure 3).

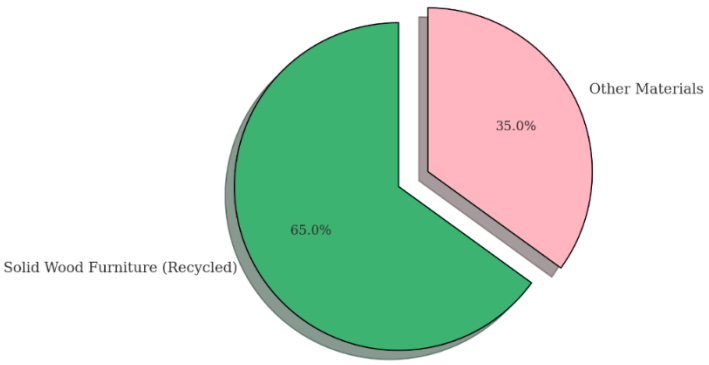

Figure 3. Percentage of Wood and Other Composite Materials Recycled.

Description of the Current Condition The chair is made of solid beech wood, which makes it sturdy and long-lasting. The seat and backrest are upholstered with fabric and padded, most likely with foam or a similar cushioning material. The surface of the wooden parts is coated with a layer of white paint. The construction is classic, featuring decorative elements on the backrest and legs. The chair includes additional crossbars to enhance its structural stability. The joints are firm; however, minor signs of wear are visible in certain areas, Figure 4. The wooden parts are in relatively good condition, with slight paint peeling and minor scratches. The upholstery is worn, showing visible signs of use and staining.In the process of recycling wooden furniture, various materials originating from old furniture are used. The chair consists of different types of materials that will be properly sorted and processed during the recycling phase: **Wood and frame construction** (legs, seat frame, backrest): solid wood with a lacquer finish.**Foam**, used as padding for the seat and backrest to ensure comfort.**Fabric and upholstery** on the seat and backrest, made of textile material. **Metal connectors,** screws, and fasteners that provide structural stability. **Lacquered surface,** as the entire wooden surface of the chair is coated with white lacquer, offering protection for the wood.

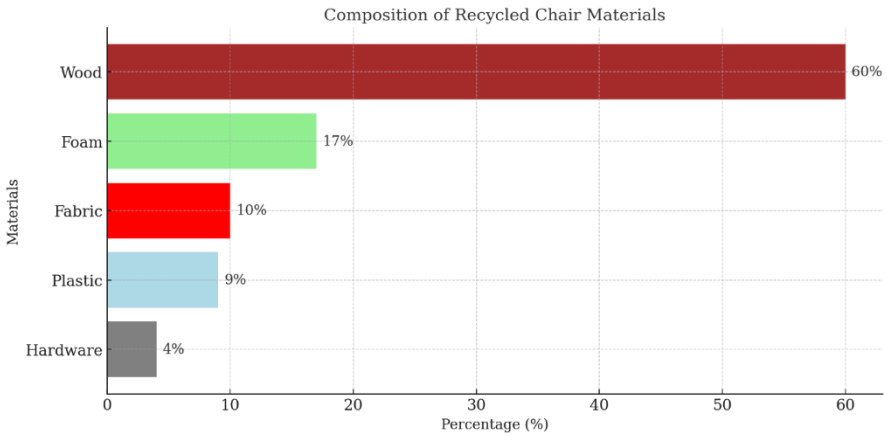

Figure 4. Percentage Composition of the Chair

The first step is the disassembly of the chair into its basic components: wood, foam, fabric, and metal connectors. Each component must be separated to be properly processed. The wooden parts are used to produce raw particleboard.Foam can be reused as cushion filling or sent for recycling. If the fabric is preserved, it can be reused; otherwise, it is forwarded for further recycling. Metal connectors are cleaned and sorted for reuse or sent to a recycling center. PVC gliders can also be reused or recycled as plastic.Although recycled materials are sometimes considered less durable than new raw materials, modern processing methods and technologies allow for the production of high-quality, long-lasting products. For example, recycled wood materials, when properly treated, can have the same (or even better) structural stability as new wood. Additionally, new treatment methods ensure that recycled furniture has a long service life, reducing the need for frequent production of new items. Many countries have developed systems for collecting old furniture through various initiatives, such as door-to-door collection and organized recycling centers. This step includes the removal of damaged and unusable furniture parts, followed by processing the remaining wooden components (sanding, nail and screw removal, cleaning off paint or lacquer) [1].

The Figure 5. represents the process from the initial analysis of the chair and the recycling procedure to the creation of a new product made from recycled material. This includes removing existing layers, stripping the upholstery and foam from the seat and backrest, separating the remaining materials, and removing layers of paint either by sanding or using environmentally friendly paint removers. All joints are inspected, and any unstable parts are reinforced.

Replacement of damaged parts of the wooden structure is carried out if necessary. The next step is the preparation for a new surface layer, which involves final sanding of the wooden parts to achieve a smooth finish. A protective layer is then applied (e.g., natural wax, environmentally friendly paint, or wood oil). Wood is a highly biodegradable material, but the recycling process enables its reuse in the production of new items, thereby reducing the need for cutting down new trees.

For example, recycled wood materials, when properly processed, can have the same (or even better) structural stability as new wood [8,9]. Furthermore, new treatment methods make it possible for recycled furniture to have a long service life, thus reducing the need for frequent production of new furniture.

Consumers are increasingly interested in sustainable products, creating space for commercial innovation and the development of new products. The growing demand for environmentally friendly items encourages companies to invest in recycling technologies and the production of furniture from recycled materials.Digital design using CAD/CAM software (e.g., SolidWorks, AutoCAD, and other tools) enables the creation of a virtual product model.

The software allows for precise simulation to optimize both the functionality and aesthetics of the product. Based on the digital model, a virtual prototype is developed, allowing for testing before proceeding to the production of the physical prototype [7,10].

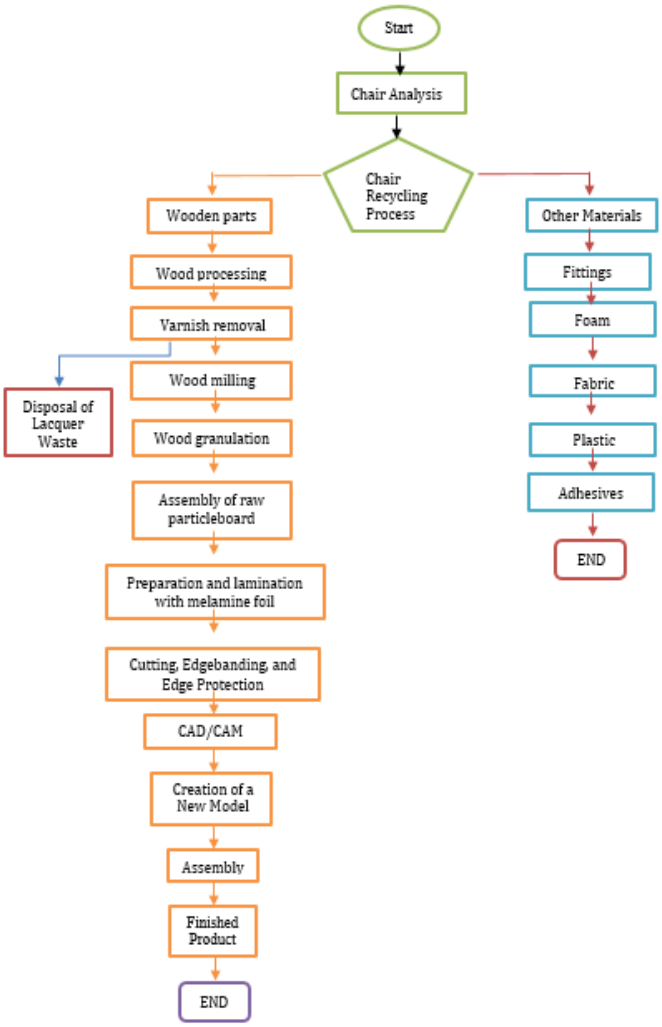

Figure 5. Information Flow Diagram of the Chair Recycling Process

After digital simulations, the process continues with testing and optimization to achieve maximum efficiency and product longevity. The results show that the recycling process, through the use of appropriate materials and methods, yields significant outcomes (Figure 6).

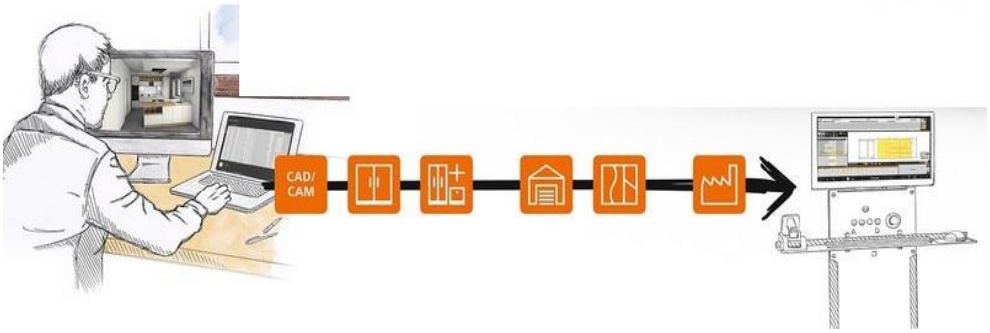

Figure 6. CAD/CAM Construction of New Products from Recycled Boards

3. Result

In this research, we analyzed the recycling process of chairs made from solid wood and the potential for their reuse in the production of particleboard. The objective was to determine how many chairs need to be recycled to obtain a sufficient amount of raw particleboard for manufacturing a standard-sized wardrobe (800 mm x 1000 mm x 500 mm).

This study highlights the need for continuous improvement of recycling methods, raising awareness about the importance of material reuse, and developing sustainable technologies. Future advancements in the field of recycling should focus on integrating innovative solutions, improving efficiency, and increasing the share of recycled materials in industrial production. Given the growing demand for environmentally friendly products, recycled wood materials hold significant potential for further application in modern design and the furniture industry [11,12]. Data Collection Each recycled chair contributes approximately 0.5 m^2 of raw particleboard, providing around 2.5–3 kg of wooden material. By converting the wood into sawdust for particleboard production, about 2 kg of usable raw material is obtained per chair.In the manufacturing of raw particleboards, one chair can yield approximately 0.5 m^2 of board with a thickness of 18 mm.

To produce a standard-sized wardrobe (800 mm x 1000 mm x 500 mm), approximately 8–10 m^2 of particleboard is required. This means that around 16 to 20 chairs must be recycled to obtain a sufficient amount of material. A horizontal bar chart visually represents how many chairs are needed for the production of one or more wardrobes, depending on their size and board usage (Figure 7).

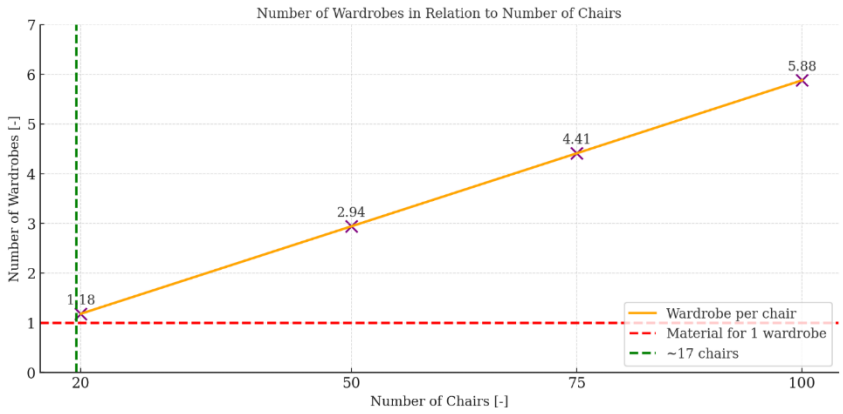

Figure 7. Diagram of the Number of Chairs Required for One or More Wardrobes

The chart now clearly shows how many wardrobes can be produced from:

- 17,5 chairs ≈ 1 wardrobe
- 20 chairs ≈ 1,18 wardrobes
- 50 chairs ≈ 2,94 wardrobes
- 75 chairs ≈ 4,41 wardrobes
- 100 chairs ≈ 5,88 wardrobes

The research results clearly highlight the key aspects of recycling wooden chairs and their use in the production of wardrobes. Recycling chairs is both economically and environmentally beneficial. Each chair can contribute to the production of 0.5 m^2 of raw particleboard, meaning that instead of discarding old furniture, a new product can be created. The recycling process reduces the need for new raw materials and lowers CO_2 emissions.

The relationship between the number of chairs and the number of wardrobes is linear – as the number of recycled chairs increases, the number of wardrobes that can be produced increases proportionally. On average, 16–20 chairs are required to produce one wardrobe.If more wardrobes are to be produced, the number of chairs needed rises in the same ratio, as shown in Figure 7.

Environmental benefits of recycling include a reduction in landfill waste. Instead of becoming waste, wooden parts of chairs are shredded and reused, contributing to the circular economy and sustainable development. The potential to optimize the recycling process lies in establishing a systematic approach to recycling wooden furniture, which can significantly reduce the demand for new wood resources. By increasing recycling efficiency, it is also possible to lower the production costs of new products [13,14].

4. Conclusion

The graphical representation and data confirm that chair recycling can create a sustainable production process, reducing negative environmental impacts while ensuring the functional and economic usability of wooden material.Furniture recycling represents a key step toward waste reduction and smarter use of natural resources. Recycling wooden furniture, such as chairs, serves as a practical example of applying circular economy principles in everyday life and industry [15,16].

The recycling process of this solid wood chair demonstrates how functional yet worn-out pieces of furniture can be transformed into high-quality new products, significantly contributing to resource conservation and waste reduction. The chair featured a solid wood frame coated with paint, while the seat and backrest were upholstered with fabric and foam padding.Its disassembly enabled proper material sorting, where the wood was shredded and processed into raw particleboards, while the metal fittings, foam, and fabric were sorted and treated according to appropriate recycling methods. The final result was the creation of a functional wardrobe, achieving multiple benefits environmental, economic, and social highlighting the broad advantages of recycling. The environmental sustainability of chair recycling reduces the amount of waste and prevents materials from ending up in landfills.

This directly contributes to the preservation of natural resources and the reduction of the ecological footprint. By transforming an old chair into new products, the costs of acquiring new raw materials are reduced [17,18]. In addition, recycled products are increasingly in demand on the market due to their sustainability and quality. Solid wood from the chair, when properly processed and reused, can possess the same-or even better-properties than new wood [19,20].

This process extends the material's lifespan and increases its value. With new innovations in digital modeling and CAD/CAM technologies, it is now possible to precisely plan and produce virtual prototypes, minimizing production errors and optimizing the use of resources.

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The Impact Of Abrasive Grain Size On The Roughness Of Solid Wood Surfaces During Sanding On A Cylindrical Grinder At Doo "Bor" Bihac

Šehić Amina* **and Hrnjica Samra**

Faculty of Technical Engineering, University of Bihać, Bihać, Bosnia and Herzegovina

* E-mail: aminasehic2016@gmail.com

Abstract. The technological operation of grinding achieves high productivity, which is conditioned by the development of new technologies and materials. The first operation in this surface treatment of wood is sanding, which is used to reduce the roughness of the treated surface as much as possible and to remove the nerves caused by the previous treatment. Grinding is a complex material processing process that depends on various factors, such as the type of material, the granulation of the grinding material, the grinding speed, as well as the correct grinding pressure. In this paper, the influence of the size of the grinding material grain on the roughness of the processed surface of the massiv during grinding on a cylindrical grinder will be investigated, based on the size of the roughness parameters Ra and Rz of the experiment conducted in the company d.o.o. "BOR" Bihac. The goal of this research is to analyse how the granulation of the grinding material affects the roughness of the machined surface and how to optimize the grinding process based on that, while achieving the desired processing quality.
The statistical processing of the results of the experiment, which was carried out essentially applied, will show the effectiveness of grinding for different sizes of grinding grain, including grinding speed, costs and processing time.

1. Introduction

Sanding wood is the most important operation for correcting certain roughnesses caused by previous treatments. Sanding has the greatest impact on coating adhesion and surface roughness, and consequently on the smoothness of the final details. The sanding process varies depending on the type of wood, the final coating to be applied, and other factors. To achieve satisfactory sanding results, it is important to carefully select the parameters of the sanding process, including the characteristics of the abrasive material. Some key influencing factors include the type of material, the grit size of the abrasive, sanding speed, and proper pressure. Other relevant aspects include cooling, type of sander, shape, size and requirements of the workpiece surface, and the operator's experience.

One of the crucial factors affecting the final quality of the processed surface is the grit size of the abrasive material. Sanders are tools with various applications, differing based on their type and purpose, whether used for grinding, cutting, polishing, or shaping different materials. Rectangular sanders are used for cutting, sanding, and polishing in hard-to-reach areas, while belt sanders efficiently process large surfaces and remove material. Bench grinders are used for sharpening tools and fine processing, while cylindrical grinders are used for processing cylindrical surfaces and the interior of cylinders. Surface grinders allow for precise leveling and grinding, and centerless grinders are applied in the automotive industry for grinding cylindrical parts without a central axis. Stone and concrete grinders use diamond plates for grinding hard materials. Electric grinders adapt to various tasks with different discs, while wood sanders are specifically designed for processing wood and leveling large surfaces.

When selecting a sander, it is important to consider the specifics of the task and the material to be processed. The company “Bor” d.o.o. began its operations in the early 1960s as a craft workshop, under the ownership and management of Hasan Mujnovic. Today, the company “Bor” includes the production of facade and interior joinery, staircase cladding elements, and interior components. This scientific research paper investigates the impact of abrasive grain size on the surface roughness of solid wood during sanding on a cylindrical sander, through an experiment conducted at the company “Bor” d.o.o. The aim of the research is to thoroughly examine how different grain sizes affect the quality of the processed surface, with a special emphasis on optimizing the sanding process to achieve better quality and more efficient production in the company. The research includes a comparison of sanding efficiency for different grain

sizes, including sanding speed, material costs, and processing time. It also determines certain optimal parameters for sanding with different grain sizes in order to achieve the desired surface quality and ensure maximum productivity. In addition to the technical aspects, the paper also analyzes the economic impact of using different grain sizes, including material costs, time, and potential savings. Furthermore, the safety and environmental aspects of sanding are examined, such as dust emission and material handling. Based on the research results, recommendations are formulated for application in a real industrial environment in order to improve processing quality and efficiency.

This paper is based on the analysis of experimental results, the study of relevant literature, and consultations with experts in the field of material processing. The following chapters explore relevant theories and research methods in more detail, and also analyze the obtained results and provide recommendations for improving the sanding process in the company "Bor." With the hope that this research contributes to the development of sanding technology and the optimization of solid wood surface treatment processes.

2. Experimental research

At the company "Bor" d.o.o., an experiment is planned in which sanding will be performed on an SCM brand cylindrical sander using different types of wood and various abrasive materials. Based on this, the roughness of the sanded surface will be evaluated in relation to the average roughness value (Ra) and the maximum roughness value.

2.1. Required resources

This experiment requires specific resources, including sandpaper, a wide-belt sander, a surface roughness measuring instrument, and three types of wood: spruce, beech, and oak. Sandpaper is a tool used for sanding and polishing various materials. It consists of a paper or fabric backing onto which a layer of abrasive material is applied. The abrasive material comes in different grit sizes, which determine the coarseness or fineness of the sandpaper. Sandpaper is available in various grit levels, indicated by numbers. Lower numbers represent coarser sandpaper, while higher numbers indicate finer sandpaper. For example, sandpaper labeled 60 is used for rough sanding, whereas sandpaper labeled 400 or higher is suitable for fine sanding or polishing. There are two types of sandpaper coatings: open coat and closed coat. Open-coat sandpapers have spaces between abrasive grains, which helps prevent clogging and extends the paper's lifespan. These are commonly used for wood sanding. Closed-coat sandpapers have densely packed abrasive grains, making them suitable for sanding metals and other hard materials. Sandpaper is widely used for wood processing, removing surface irregularities, smoothing surfaces, and shaping wooden components. It comes in the form of rolls, belts, sheets, or discs, and the choice depends on the specific needs of the application.

The selection of the correct sandpaper depends on the type of material being processed, the desired outcome, and the specific sanding application. The sanding machine, also known as a wide-belt sander, is a tool used to remove material from a surface in order to achieve the desired shape, smoothness, or finish. There are different types of sanders, adapted to specific tasks and materials being processed. The technical specifications of the wide-belt sander include motor power, belt width, belt speed, as well as the ability to adjust the sanding depth. The technical specifications of the wide-belt sander include a total power consumption of 70 kW and a machine weight of 7,500 kg. The thickness of the wooden element must be in the range of 3 to 160 mm, while the sanding width is 1,350 mm. Sanders are often used for surface preparation before painting, varnishing, or applying other coatings.

Figure 1. Wide-Belt Sander photographed from a wider angle

Sanding can remove excess material, burrs, oxidation, or irregularities from various materials. It is also used to shape materials according to specific dimensions or forms. Proper installation of the sanding tool or paper and following the usage instructions are crucial for safe operation. Additionally, regular maintenance and cleaning of the sander are very important for its preservation. The roughness measuring instrument TMR120, used to measure the surface roughness of materials, enables precise measurement of various roughness parameters, which is important in many industries, including metallurgy, engineering, manufacturing, and others.

Figure 2. Surface Roughness Measuring Instruments TMR 120

Roughness measurement is carried out using a piezoelectric microprobe, in the same way as with precise laboratory instruments. After pressing the button, the piezoelectric microprobe scans the surface and displays the roughness value on the screen within a few seconds. Surface profilometers use various techniques to measure roughness, including contact and non-contact methods. In contact methods, the sensor or probe physically touches the surface and records height variations. Non-contact methods use optical or laser sensors to analyze the surface without physical contact. These devices measure parameters such as Ra (average arithmetic roughness), Rz (average maximum height of the profile), Rt (maximum profile height), and other relevant characteristics. Profilometers are used in many industries for quality control, surface condition assessment, and ensuring compliance with roughness standards. They are especially valuable in engineering and materials science sectors, where they enable detailed study of material surface properties. Their use is also crucial in the maintenance of machinery, tools, and other

industrial equipment, as they allow monitoring of wear and surface degradation. There are two main types of profilometers: contact and non-contact. Contact profilometers use physical probes tailored to specific measurement needs, while non-contact profilometers utilize advanced optical and laser technologies for precise scanning and surface analysis. Regardless of the type, these devices are essential for industries that require high precision in roughness measurement to ensure product quality and meet specific technical standards. Additionally, modern profilometers often come with advanced software solutions that enable deeper data analysis, creation of 3D surface models, and integration with other quality control processes, further enhancing measurement efficiency and reliability.

2.2. Experimental Procedure

The experiment was planned by selecting samples of three types of wood: fir, beech, and oak, along with three sandpaper grits (120, 150, 180). The aim of the experiment was to determine the impact of wood type on the quality of the final surface finish. Special attention was given to the sanded, clean workpieces and their dimensional specifications used for these measurements. It is also important to highlight the sanding parameters, primarily the cutting speed and feed rate of the workpiece, as these significantly influence the final machining result and the achievement of the desired surface finish.

Table 1. Experiment Plan

Rb	Type of wood	Grit of Sandpaper	Ra			Ra	Rz			Rzs
P1	FIR WOOD	120								
P2	BEECH WOOD	120								
P3	OAK WOOD	120								
P4	FIR WOOD	150								
P5	BEECH WOOD	150								
P6	OAK WOOD	150								
P7	FIR WOOD	180								
P8	BEECH WOOD	180								
P9	OAK WOOD	180								

Nine measurements were conducted according to the experimental plan in Table 3.1, and the obtained results will be statistically processed and analyzed in the following chapter. By selecting the parameters to be included, carrying out the experiment, and performing the associated activities, the research objective will be achieved. This experiment investigates three different types of wood. The characteristics of the measuring device used include high accuracy, wide range of applications, ease of use, and stable performance. When the device is activated, it moves uniformly across the surface. The contact stylus moves up and down vertically along the working surface. This movement is converted into electrical signals, which are amplified, filtered, and converted into digital signals via A/D conversion. The signals are then processed by a DSP into Ra and Rz values before being displayed on the screen.

2.3. Experimental results

As part of the experiment, a total of nine measurements are performed according to a predefined plan. The cutting speed used throughout all phases is 28 m/s, while the feed speed of the workpiece is 1.8 m/min, enabling consistent and precise machining results.

Table 2. Experimental Results

Rb	Type of wood	Grit of Sandpaper	Ra(μm)			Ra	Rz(μm)			Rzs
P1	FIR WOOD	120	3,91	4,76	4,42	4,36	17,68	27,00	23,10	22,55
P2	BEECH WOOD	120	5,44	4,76	3,06	4,42	28,70	23,90	14,10	22,28
P3	OAK WOOD	120	3,23	3,74	2,38	3,11	17,85	23,60	15,30	18,91
P4	FIR WOOD	150	3,23	2,38	4,25	3,28	16,85	12,58	23,80	17,73
P5	BEECH WOOD	150	2,72	4,08	3,06	3,52	14,96	25,80	18,70	19,82
P6	OAK WOOD	150	1,85	2,90	4,20	2,98	24,45	17,43	11,01	17,63
P7	FIR WOOD	180	3,23	3,57	2,04	2,94	17,17	20,40	11,90	16,49
P8	BEECH WOOD	180	3,91	4,08	2,72	3,57	22,91	20,71	11,49	18,37
P9	OAK WOOD	180	2,55	2,72	3,06	2,77	14,28	16,19	19,04	16,60

The workpieces made of fir, beech, and oak have identical dimensions of 800x100x25 mm, ensuring equal conditions for all wood types. These parameters enable precise examination of the influence of wood type and sandpaper grit size on surface finish, providing a basis for further surface quality analysis. In the previous Table 3.2, the measurement results of Ra and Rz were presented for the three wood types, sanded using three different sandpaper grits, at three different speeds. Three control measurements were performed, from which the average values of Ra and Rz were calculated for each wood type.

3. Analysis and statistical processing of results

After the practical execution of the experiment, which included sample preparation and measurement of the roughness of the processed surfaces, as well as calculation of the average values of the Ra and Rz parameters, a detailed analysis of the experimental results was conducted. The goal of this analysis is to determine how various parameters, such as sandpaper grit size, feed speed, and wood density, affect the quality and roughness of the processed surfaces, thereby enabling optimization of the sanding process to achieve the best possible results.

Based on the statistical analysis of fir wood data, it can be observed that the average value of the Ra parameter (arithmetical mean deviation of the profile) shows interesting patterns depending on the grit size of the sandpaper used. When sandpaper with a grit size of 180 was used, the lowest Ra value was recorded, indicating that this grit size allows achieving a smooth surface with reduced roughness.

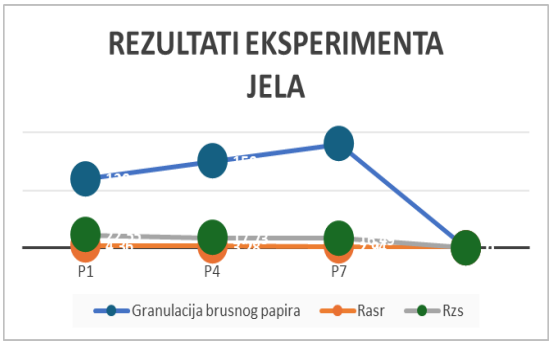

Figure 3. Experimental results for fir wood

On the other hand, with sandpaper grit 120, the highest Ra value was recorded, suggesting that this grit is too coarse to achieve the desired surface quality. A similar trend can be observed for the Rz parameter (maximum height deviation of the profile), where the lowest value was also recorded at grit 180, and the highest value at grit 120. These results indicate that finer sandpaper grits, such as 180, contribute to better finishing and higher quality surface properties. These findings are crucial for further optimization of the sanding process and the selection of appropriate materials depending on the desired characteristics of the treated surface.

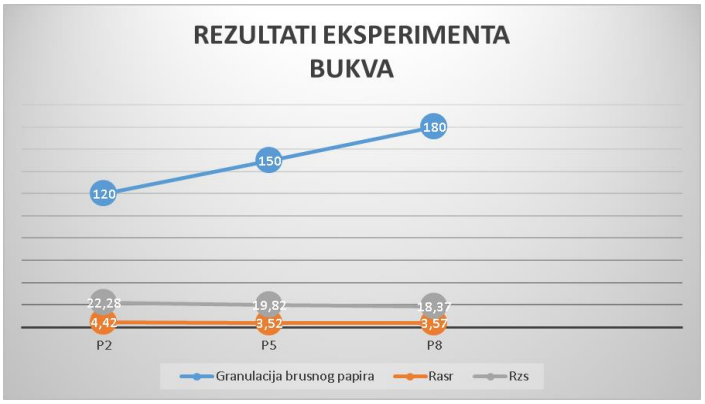

Figure 4. Experimental Results for Beech Wood

Based on the statistical data for beech wood, it is observed that the average value of the Ra parameter reaches its lowest value at the abrasive paper grit of 150, while the highest value corresponds to the grit of 120. Regarding the Rz parameter, the lowest value was recorded at the grit of 180, whereas the highest value was present at the grit of 120.

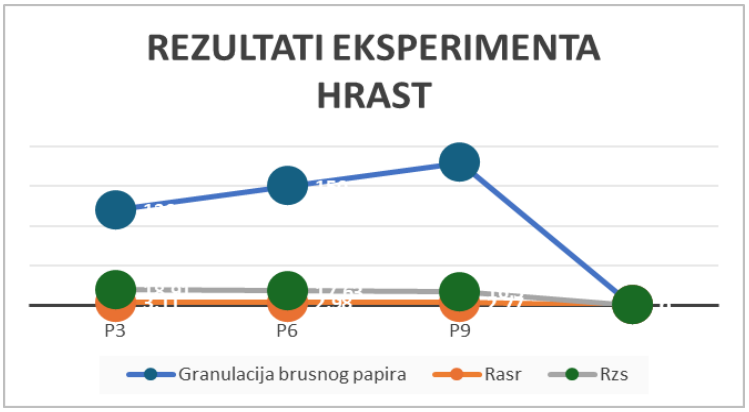

Figure 5. Oak Experiment Results

According to the presented statistical analysis, it can be seen that the average Ra value (Rasr) at the 120 grit sandpaper is lowest for oak, measuring 3.11, followed by spruce at 4.36, and the highest value is for beech at 4.42. Regarding Rz values at the 120 grit, oak also has the lowest value at 18.91, followed by beech at 22.28, and the highest value is for spruce at 22.55. For the 150 grit sandpaper, the highest average Ra (Rasr) was recorded for beech at 3.52, spruce at 3.28, and the lowest value was for oak at 2.98. Regarding Rz at the same grit, the value for spruce is 17.73, for beech 19.82, while the lowest is for oak at 17.63. At the 180 grit sandpaper, the lowest average Ra (Rasr) is for oak at 2.77, followed by spruce at 2.94, and the highest value is for beech at 3.57. As for Rz, the lowest value was recorded for oak at 16.50, followed closely by spruce at 16.49, while beech has the highest value at 18.37.

Based on this statistical analysis, it can be concluded that the sandpaper grit significantly affects the Ra and Rz parameter values for different wood species, including oak, spruce, and beech. Different grit sizes result in varying levels of surface roughness, which is clearly reflected in the variations of average Rasr and

Rzs values. For example, at grit 120, oak shows the lowest values for both parameters, while beech and spruce have higher values.

A similar trend is observed for grit sizes 150 and 180, where each grit shows specific values for each type of wood. These differences indicate that choosing the appropriate grit size of sandpaper is crucial for achieving the desired surface quality, and the effect varies depending on the type of wood.

This suggests that the processing must be adapted to the specific characteristics of the material. Statistical data clearly show that different grit sizes have varying effects on the roughness of oak, spruce, and beech surfaces, and this must be taken into account when planning and performing the processing. For the sandpaper grit size of 120, the roughness characteristics of the wood in relation to density are shown in the diagram below, Figure 3.4.

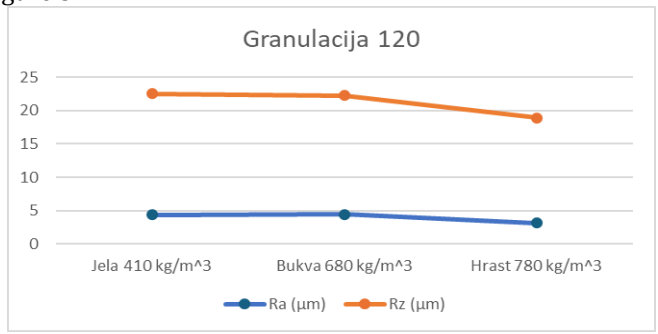

Figure 6. Roughness measurement results at grit size 120

For the granulation of paper, the characteristics of wood's elasticity in relation to wood density are shown in the diagram below.

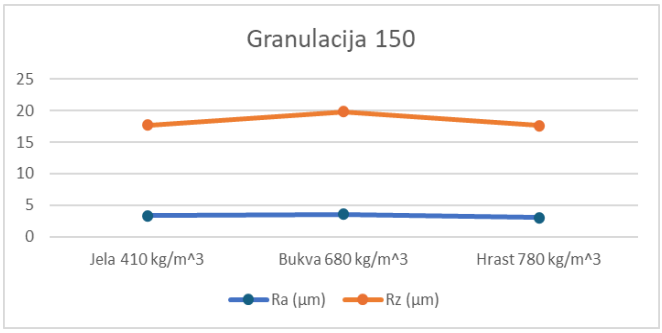

Figure 7. Roughness measurement results at grit size 150

The diagram below (Figure 8.) shows the roughness characteristics of the wood in relation to its density for the grit size 180 sandpaper.

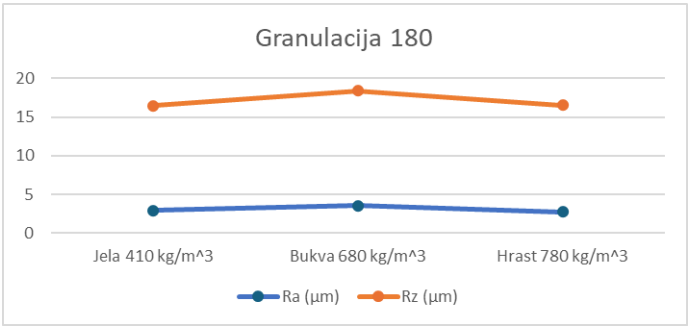

Figure 8. Roughness measurement results for grit size 180

The wood density values for spruce, beech, and oak were taken from the literature, and the changes in roughness parameters in relation to wood density (ρ) are presented. Wood density plays a key role in determining the quality of the final surface treatment and the roughness of the workpieces.

Each type of wood has unique characteristics, and density is one of the most important parameters influencing the mechanical properties of the material. In this experiment, three types of wood were analyzed: spruce, beech, and oak, which differ in their density. High wood density, such as that of oak, can positively affect the quality of the surface finish. Harder materials generally exhibit greater resistance to mechanical damage during sanding, leading to lower roughness values (Ra and Rz). Due to their structure, woods with higher density often allow for smoother sanding, as the abrasive particles make better contact with the surface, reducing the possibility of irregularities and damage.

On the other hand, wood species with lower density, like spruce, are more susceptible to damage during sanding. Lower resistance to mechanical impacts can result in higher roughness values because the surface is more easily damaged and deformed. This leads to irregularities on the processed surface, negatively affecting the final appearance and quality of the product. In this context, wood density affects not only the sanding process itself but also the selection of appropriate processing parameters, such as cutting speed and abrasive grit size. To achieve optimal surface quality, it is important to understand this relationship and adjust the processing techniques according to the specific characteristics of each wood type.

4. Conclusion

The process of sanding wooden surfaces is carried out in several stages, using sandpaper of various grits. This procedure allows for the gradual removal of irregularities, where coarser grits are first used for rough sanding, followed by finer grits for finishing. In addition to the grit of the sandpaper, the quality of the treated surface is significantly influenced by the feed rate of the wooden workpiece during sanding on machines, as well as the density of the wood.

The roughness of the surface has a significant impact on the strength and durability of the material. Greater roughness leads to a reduction in dynamic endurance, meaning that the material is more susceptible to damage during use. Surfaces with lower roughness exhibit better adhesion and heat transfer capabilities, which is particularly important for lacquered and other finished surfaces.

Experimental research on the grinding process of three different types of wood with varying densities, using three feed rates and three grits of sandpaper, provided insight into the impact of these parameters on surface roughness. It was concluded that wood density, feed rate, and sandpaper grit are key factors determining surface roughness.

With the increase in wood density, an increase in surface roughness has been observed, specifically higher values of the parameters Ra and Rz. This suggests that denser woods achieve smoother surfaces more difficultly during sanding. The use of sandpaper with a higher grain reduces surface roughness, as finer grains allow for more precise processing and removal of smaller irregularities. The effects of feed speed appear to be more complex: while an increase in speed slightly increases Ra, the Rz parameter slightly decreases, indicating that surface roughness generally decreases at higher speeds.

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Research on Augmented Reality Application Development Software

Alema Husić

Technical faculty, University of Bihać, Bosnia and Herzegovina

E-mail: alemahusic@gmail.ba

Abstract. This paper describes the use of different software for creating mobile and web applications that use augmented reality (AR). With the development of technology, augmented reality is increasingly being used in various areas such as education, marketing, tourism and industry. Like any other technology, augmented reality has its own challenges and limitations that can be overcome by using appropriate software. This paper focuses on the analysis and application of corresponding software such as 8th wall, AR Foundation and Lightship which are based on the simultaneous localization and mapping (SLAM) algorithm.

Keywords: augmented reality, Lightship, 8th Wall, AR Foundation

1. Introduction

With the advancement of technology, humans have increasingly sunk into the virtual world and detached from reality. In order to create a balance between these two worlds, Ivan Sutherland introduced the first concept of augmented reality as early as the 1960s. Due to technological limitations, this concept only came to life in 1992. when the term augmented reality (AR) was used for the first time in the work of Tom Caudell and David Mizell. They were trying to create a system that would assist workers in assembling parts using visual instructions at the Boeing company [1].

Since then, augmented reality has advanced significantly and is now used in everyday areas of life: from industry, education and tourism to marketing, video games and entertainment. However, as it evolves, there is an increasing need for more complex and advanced applications. In order to develop an application based on augmented reality, it is necessary to know some basic concepts, algorithms and software that are the basis of AR applications, as well as their capabilities and limitations [2].

One of the biggest challenges with AR apps is device compatibility. It is important to note that mobile devices with operating systems older than Android 7.0 will not be able to properly run AR apps and view AR content. Another challenge is that many people avoid downloading apps to their devices, which can affect the popularity of the app [3].

Augmented reality apps can be either simple or very complex. Simple applications can be created to be accessible to everyone via a web browser. More complex applications contain many more elements and have greater capabilities. Some software allows the use of visual positioning and mapping systems, occlusion, multiplayer, motion tracking and many others. Such applications must be downloaded to the device and are created using more demanding software such as AR Foundation and Lightship [4].

In this paper, a study was conducted on the 8th Wall software for web applications, as well as on AR Foundation and Lightship for Android devices. Lightship has an additional feature that allows placing 3D models in real-world locations with an accuracy of just a few centimeters called Visual positioning system (VPS). An application was created for each of these software and measurements and analyses of their performance on various mobile devices were performed.

2. Materials and methods

To research the software used to create AR applications, it is first necessary to define which software will be processed. The aim of this paper is to present several software used to create different applications and their capabilities. For more demanding applications that have greater capabilities, Unity software and AR Foundation and Lightship technologies are used. These technologies are based on the Simultaneous localization and mapping (SLAM) algorithm and use the method of scanning the users environment, determining the geographical position using the camera, gyroscope and GPS of the mobile device, and simultaneously creating a 3D map of the environment that will be used to realize augmented reality [5]. To use these technologies, it is necessary to use Unity software, which is based on programming in C#, so it is very important to implement AR applications in that programming language. The official Unity documentation for AR Foundation was also used [6].

The method of placing a digital 3D object at a specific location in the real world is called Visual Positioning System (VPS). For applications based on VPS, it is necessary to use the Niantic Wayfarer application to create a scan of the geographic location where you want to place the 3D model in augmented reality. It is an official application of the company Niantic Labs, which is the creator and owner of the Lightship software. It is necessary to create several scans of the location that is to be used in the application at different time intervals and upload them to Niantic's cloud database. After a few days, it is possible to download the VPS model of the scanned location via the Geospatial browser on the Lightship website. Downloading the VPS model is a key part of the implementation of the application. The application was created using instructions from the Niantic documentation for Lightship 3 [7]. For applications that are based on web browsers, i.e. do not need to be installed on a mobile device, the 8th Wall software is used. It allows the creation of simpler applications and is increasingly used in marketing. 8th Wall is based on the WebAR SLAM (simultaneous localization and mapping for the web) algorithm that uses the same method as SLAM for Lightship and AR Foundation, only adapted for display on the web. Using the 8th Wall software is very simple, but in some cases it is necessary to know and use the JavaScript programming language and its library for displaying 3D objects on the web Three.js. When importing the 3D model into the project, a problem arose because the created 3D model took up over 100 MB, so only the basic parts of the texture were taken, for the color, in order to reduce the space it takes up. Parts of the texture for depth, reflection and 3D effect were discarded. The 8th Wall official documentation was also used [8].

Besides the mentioned ones, there are several other software for creating AR applications, such as Vuforia and Wikitude, which are software development kits (SDKs), as well as Lightship and AR Foundation. their comparison with the used software is shown in Table 1. The parameters that were observed are the platforms they support, the type of development environment, and some of the most important features they enable and their limitations [9].

AR Foundation and Lightship were chosen for the research due to their free access and advanced features. 8th Wall, although it has limitations for free use, has a special feature of creating AR content for the web and was considered worthy of research.

Table 1. Comparison of the software used in this paper with other popular AR developing tools

Tool	Platform	Type	Strengths	Limitations
8th Wall	Web, mobile	WebAR	No app needed	Limited free tier
AR Foundation	iOS, Android	SDK	Cross-platform Unity support	Complex for beginners
Lightship	iOS, Android	SDK	VPS, occlusion	Reliance on Niantic's infrastructure
Vuforia	Android, Windows	SDK	Robust tracking	Limited free tier
Wikitude	Android, Windows	SDK	GeoAR, object tracking	Paid license

In addition to the aforementioned software and methods that they use to create an AR application, it is necessary to prepare a 3D object that will be displayed in the extended application [10]. The software used to create the 3D model is called Blender [11]. A 3D model of the Sokolac Tower located in Bihać was created, Figure 1. During the modeling, photographs, diagrams and blueprints of the tower were used to make the model look as realistic as possible.

Figure 1. The 3D model of Sokolac castle (Bihać) that was created using Blender software and is placed in augmented reality in each of the developed applications

Physically-based Rendering (PBR) textures were used for texturing and UV mapping of the model, which gives a realistic look that has depth and shine in addition to color [12]. Each of these textures consists of elements that are essential for achieving realistic textures, Figure 2 [13]. The PBR textures were downloaded from the Poly Haven website [14].

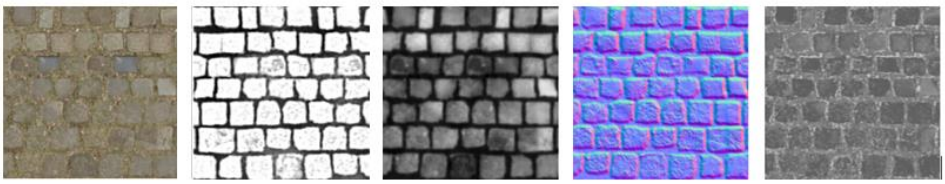

Figure 2. Texture parts used to key the walls and tower of the 3D model: a) color, b) ambient occlusion, c) displacement, d) normal map, e) roughness

The final method used in the realisation of this topic involves testing the developed applications and evaluating the results. The main goal of the tests is to evaluate the practical capabilities of each AR development platform in terms of performance, tracking accuracy, user experience across various devices and conditions such as lighting, hardware and other parameters that affect the AR experience itself. In doing so, it is necessary to use a suitable mobile device that supports augmented reality. The apps were tested on three different devices: Samsung Galaxy A10s, Samsung Galaxy A50 and Xiaomi Redmi Note 11 Pro. The specifications of these devices are shown in Table 2.

Table 2. Specifications of the devices used for application testing

Device	RAM	Processor	Internal memory	OS

Samsung Galaxy A10s	2 GB	MediaTek Helio P22	32 GB	Android 9
Samsung Galaxy A50	6 GB	Exynos 9610	64 GB	Android 11
Redmi Note 11 Pro	8 GB	MediaTek Dimensity	128 GB	MIUI 13 (Android 12)

From the table, it can be seen that mobile devices with different specifications and capabilities were taken to ensure a comfortable use for all users. In order to measure the listed parameters as accurately as possible, the Real-Time FPS Meter & Display application was used to measure refresh rate (RR) and frames per second (FPS), G-CPU to measure resource usage, and for the Note 11 Pro, the built-in tool that measures these parameters called GameTurbo is used.

3. Results

A fter developing the applications, it is necessary to analyze their correct functioning. The tested parameters are: application startup time (Tp), refresh rate (RR), time required to detect surfaces (Td), number of frames per second (FPS) and resource usage (RAM and CPU). First, the application built using AR Foundation was tested. Three tests were performed on each device. Test 1 was done with lower lighting (T1), Test 2 with good lighting (T2) and Test 3 with normal lighting (T3).

Table 3. Testing the application developed using AR Foundation

Device	Test	Tp(s)	RR(Hz)	Td(s)	FPS	Resources (%)
Note 11 Pro	T1	1.5	60	1	60	28%
	T2	1.3	60	0.8	62	34%
	T3	1.4	60	0.9	65	31%
Galaxy A50	T1	2	55	1.6	50	46%
	T2	1.7	50	1.5	49	52%
	T3	2.1	57	1.4	46	49%
Galaxy A20s	T1	12	28	17	6	100%
	T2	10	33	10	25	98%
	T3	12	30	12	12	100%

The test results are shown in Table 3. Based on the results, it can be seen that using the application is very comfortable and the results are satisfactory on devices with specifications similar to the Redmi Note 11 Pro and Samsung Galaxy A50. It does not take much time to start the application, the number of refreshes and frames per second is satisfactory, it does not take much time to detect surfaces and resource utilization is normal, the devices are not too loaded by using this application. Older devices with weaker specifications have difficulties using the application and the AR experience itself is not satisfactory. For easier understanding of the obtained test results, all results are graphically displayed in Figure 3.

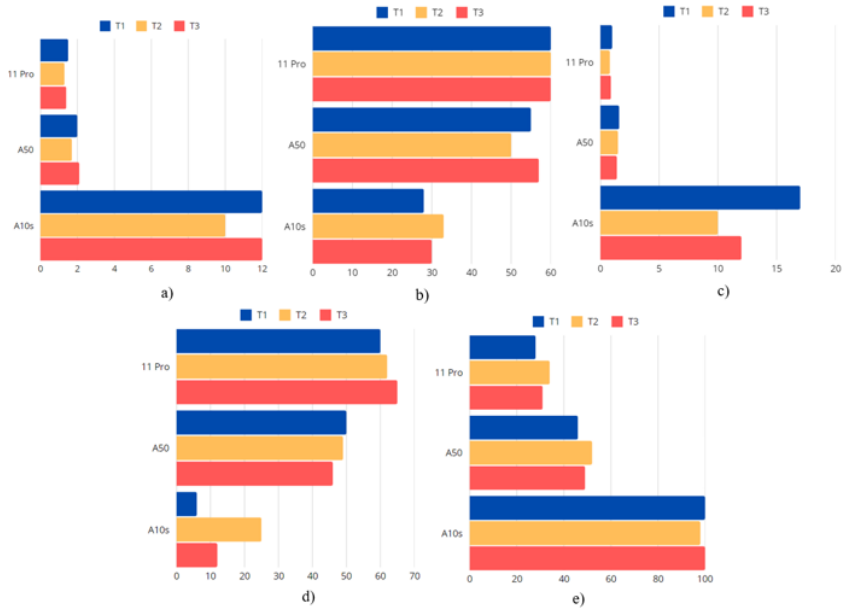

Figure 3. Results of testing the application created in AR Foundation; a) startup time; b) refresh rate; c) surface detection time; d) number of frames per second; e) resource utilization

The next tested application was the WebAR application created with 8th Wall. The startup time does not include the time needed to load the application in the web browser, but only the time it takes to launch the application. Given that the 8th Wall application was created for the web, better results are expected compared to AR Foundation and that it will place less strain on the device itself. The results are shown in Table 4.

Table 4. Testing the application developed using 8th Wall

Device	Test	Tp(s)	RR(Hz)	Td(s)	FPS	Resources (%)
	T1	2	60	2.4	60	28%
Note 11 Pro	T2	1.5	60	1.8	62	39%
	T3	1.3	60	2.7	65	34%
	T1	2	50	2.5	55	45%
Galaxy A50	T2	1.8	60	2	50	50%
	T3	2	55	2.1	55	50%
	T1	11	40	19	8	100%
Galaxy A20s	T2	8	42	10	25	97%
	T3	10	41	8	14	98%

Testing the WebAR app gave similar results to testing the AR Foundation application, with the exception that the application created in 8th Wall opened and detected surfaces more slowly. Although

slower, the application provides a pleasant user experience. The FPS might be slightly better on middle ranged devices than on the AR Foundation app. Resources usage is normal on newer devices and the overall experience is satisfactory. Using the app on older devices gives bad results and is not recommended since it doesn't give a pleasant user experience. The results are graphically presented in the diagrams in Figure 4.

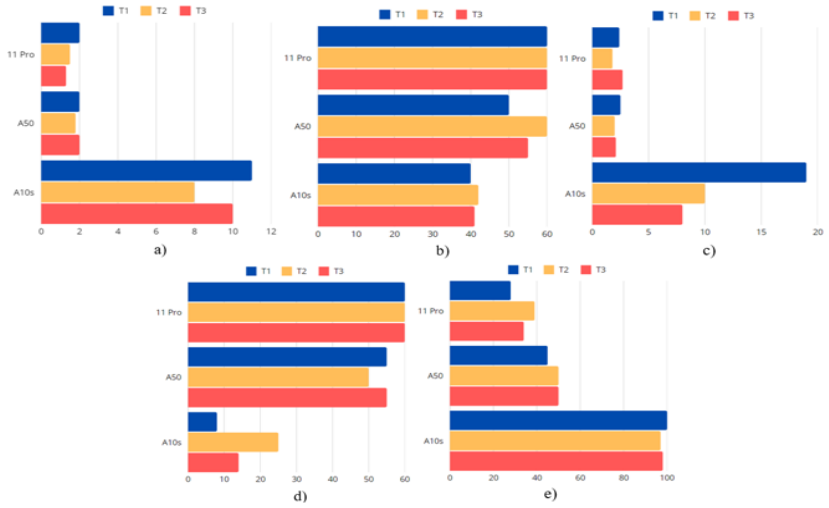

Figure 4. Results of testing the application created in 8th Wall; a) startup time; b) refresh rate; c) surface detection time; d) number of frames per second; e) resource utilization

The remaining step is to test the app developed using the Lightship software, which has the VPS technology implemented. Out of the three developed applications, this one is the most demanding, so the weakest performance is expected. The results are shown in Table 5.

Table 5. Testing the application developed using Lightship

Device	Test	Tp(s)	RR(Hz)	Td(s)	FPS	Resources (%)
Note 11 Pro	T1	4	60	3	60	63%
	T2	3	60	2	60	60%
	T3	5	60	5	60	65%
Galaxy A50	T1	5	50	6	48	83%
	T2	5	55	4	50	80%
	T3	4	50	4	50	78%
Galaxy A20s	T1, T2, T3	-	-	-	-	-%

Testing on the A10s device was not possible because its AR package is outdated and does not support newer AR content such as VPS. Upgrading to a newer AR package is also not supported. Satisfactory and expected results were obtained on other devices. The application created in the Lightship software contains more complex features and offers more options and is therefore more demanding on the device, however, this does not affect the AR experience. It takes a little longer to start the application and detect surfaces, but the refresh rate and frames per second are almost the same as in less demanding applications made in AR Foundation. Resource usage is the only parameter that is significantly higher in Lightship than in other

tested software, almost twice as high. This could affect the rapid depletion of the device's battery, which is one of the generally known problems with AR applications. In addition to the potential rapid depletion of the battery, using the application is pleasant, fast and encourages the user to leave their home to experience the VPS AR experience.

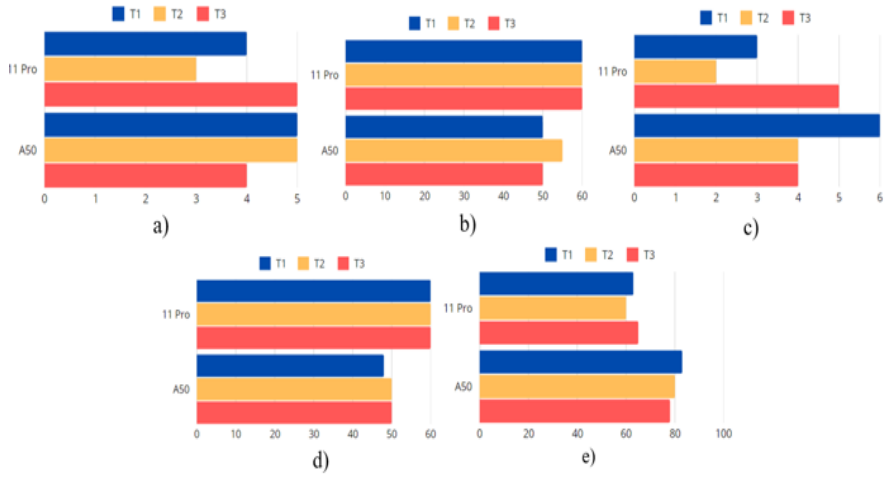

Figure 5. Results of testing the application created in Lightship; a) startup time; b) refresh rate; c) surface detection time; d) number of frames per second; e) resource utilization

Figure 5 graphically shows the results of testing the application created in Lightship software on Note 11 Pro and Samsung Galaxy S50 mobile devices. Results for the Samsung Galaxy S10s cannot be shown because that device does not support more modern AR technologies.

4.Conclusion

This paper examines three different software that enable the creation of augmented reality applications. The first software, AR Foundation, is used through the Unity program and enables the creation of complex applications. The second application was created in the 8th Wall software and is intended for use via a web browser. This software is much easier to use and requires minimal programming knowledge. Better results were expected for this application, given that it is completely web-based, but the hardware was equally loaded as in the more demanding application created in AR Foundation, and surface detection is much slower. The last tested application was created in the Lightship software. In addition to being more advanced and complex than the other software, one of the special features, VPS, was also tested in this example, and this application is much more demanding for the devices themselves. Older devices are not able to run this application, which is one of the disadvantages, and the test results, although weaker compared to the AR Foundation and 8th Wall, do not represent a major disadvantage for the average user because the AR experience itself is very pleasant.

After testing all the software, it can be concluded that they all provide satisfactory results and pleasant AR experiences, the differences in performance are small, so when choosing the software, it is best to choose the one that best meets the client's needs. For simple, easily accessible applications, it is best to use 8th Wall, and for more demanding applications, AR Foundation or Lightship. For video games and applications that require special capabilities, it is best to use Lightship, which is also the most popular of these software.

To enhance the reliability and relevance of the results, future testing should involve a broader range of mobile devices that have different hardware and operating systems. Additionally, real-user testing should be conducted with participants who were not involved in the development process for proper User Experience evaluation. Finally, it is highly recommended to carry out long term testing to monitor the app's stability and performance over time.

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Implementation and Documentation Management using D365 and dox42

Edin Akmadžić

University of Bihać, Faculty of Technical Engineering, Bosnia and Herzegovina

E-mail: edin.akmadzic@asta.ba

Abstract. This paper will focus on presenting the integration of Microsoft Dynamics D365 and the Dox42 platform for their effective management and automation of document generation, the process of collecting data on user needs for automating their processes, data flow, implementation and demonstration of the problem, as well as the advantages of these technologies. The modernization and development of many industries in the Una-Sana Canton imply a greater need for automation of various processes—including administrative processes—to facilitate work and eliminate the possibility of errors. Industries in this region still use Microsoft Excel to create all necessary documentation, whether for import or export of goods, accounting processes, employee records in the human resources department, etc. This leads to difficulties in work efficiency, data errors, and challenges in tracking information, especially when it comes to complex analyses or linking different data sources. These problems can be solved by introducing a centralized solution through Microsoft Dynamics 365 Finance and Operations (D365 FO), which enables the automation of document generation and processing, efficient data management, and improved productivity while ensuring compliance with business standards.

1. Introduction

Microsoft Dynamics 365 is a suite of intelligent business applications that help you run your entire business and achieve better results through predictive insights powered by artificial intelligence. Choose one, several, or all. Dynamics 365 applications are designed to work together – and with other systems – to provide a comprehensive solution that connects your entire business [1].

The advantage for customers, distributors, and Microsoft is that purchasing Dynamics 365 requires less upfront costs and avoids the complexity of customers and distributors having to choose from a confusing menu of available modules to determine pricing. Instead, a few basic packages include almost all the software [2]. For effective document management, it is necessary to integrate D365 with dox42.
By integrating, companies simply collaborate better, manage time better, and empower staff to be more productive, as well as to more easily identify business opportunities and weaknesses [3].

Industries have recently made significant progress in development and automation, and as a result, the need for new ways to automate processes has emerged, both in production and in administration. Modernization of processes in administration is reflected in the transition from the classic Microsoft Excel solution, which uses tables for analysis, review and data management, to a more modern, optimized system. Many programs and systems, most often called ERP (Enterprise Resource Planning systems), are emerging as a solution.

The ERP system that will be discussed in this paper is called Microsoft Dynamics 365 Finance and Operations, and its integration with the dox42 platform, in order to obtain an ideal solution for creating documentation.

The need for adequate and rapid documentation is extremely high in all industries, whether in the private or industrial sectors.

Currently, the use of Microsoft Excel tables for creating documentation represents an extremely high risk of errors, and the analysis of such data is a great challenge, because the data is organized in many tables. Dynamics 365 solves that problem by centralizing all data, that is, access to all data is not so challenging. Because of this, it is easier to make analyzes that are of great importance in all industries. Likewise, considering that the data must be written manually through Excel, and then print out such a manually written document, the level of error is extremely high. In D365, the data is updated dynamically, and the level of error has been reduced drastically.

D365 itself offers standard solutions for document printing. These standard solutions are not an adequate solution in many sectors because industries have their own requirements, rules and document design. This is where dox42 comes into the picture, which with its effective tables, dynamic data, high response speed and document design capabilities, is the ideal solution for the above problem.

A big advantage of the dox42 solution is that it allows you to design templates for Word, Excel and PowerPoint, and generate documents such as quotes, invoices, load documents, contracts, reports, presentations and diagrams, all directly from D365. Also, no programming knowledge is required – this saves a lot of time [4,5]. Both technologies are based on cloud systems, which eliminate the need for local installation of programs on computers [5].

2. Materials and methods

For this research, it is necessary to perform and present an analysis of creating a document called a load document. The first phase of implementation represents a detailed understanding of the user's needs, where the users will explain what exactly they want. This is called the planning phase. In this phase, the so-called Solution Architects collect data from the user, and define whether these fields already exist in D365, or if they need to be added. This requires the support of programmers. After this phase, it is necessary to create a requirements specification, i.e. a detailed document that represents instructions for programmers what needs to be added, or what data needs to be sent to the dox42 server. In the case of a load document, most of the data is already present in D365, such as addresses, dates, truck plates, and the like.

The methods that will be used in this paper represent the integration of D365 with dox42, and the analysis of the implementation of a document called the load document, which is the most important document that goes to customs, because it contains information about the address of the sender, recipient, delivery date, and information about the contents of the truck.

The integration is done by downloading and installing the Dox42 add-on for D365. After this step, the Dox42 server needs to be configured and recognized within D365. This is done by entering the necessary data about the newly configured server in the D365 module, called Dox42 parameters, such as URL, username, password.

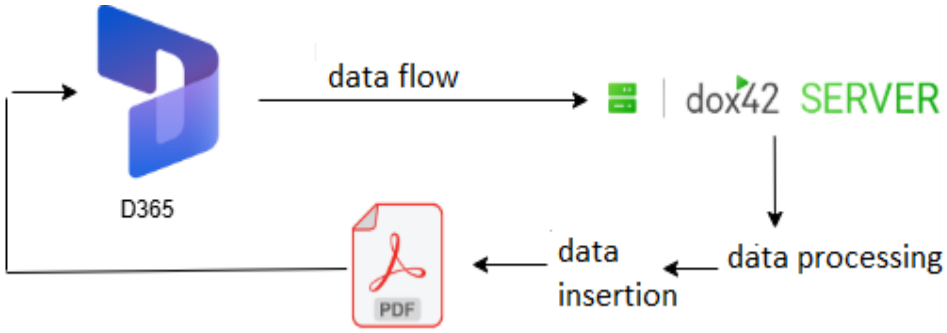

Figure 1. Data flow between Dynamics 365 and Dox42.

Likewise, it is necessary to install Dox42 Add in for Word, Excel and other programs on the server. All this is done so that data can move between Dox42 and D365.

Figure 1 shows a simple data flow diagram. Data will be sent from D365 to the Dox42 server, which will then process it through Dox42 Add-ins in Word or Excel to fill in the data in the specified places. Once this is done, the finished document is sent back to D365 where it is displayed to the end user as a document containing dynamic data that is organized according to the user's requirements.

All data sent to dox42 is organized into tables. Access to these tables is done via the Dox42 Add in for Word. Within Word, it is necessary to create a template for static text, and then add dynamic data. This dynamic data needs to be designed and processed in a way that it meets the user's requirements for printing documentation. For example, users may want different data formats or text than what is found in D365. Dox42 enables this through dynamic management of all data, where it is possible to manipulate the printout based on set conditions. In this way, the documentation is created and ready for printing [9,10].

With this process and these technologies, creating a very complex and time-consuming document has become possible with the push of a button.

3. Results

To analyze the results, the time of creating the document through Microsoft Excel and through D365 will be taken into account (the entire process will be taken into account). The data was collected on the basis of a survey.

The first piece of information is the time spent on the final goal. Therefore, a comparison of the time needed to create a document is shown in Table 1.

Table 1. Time consumption of creating a document.

Method	Document name	Completion time (min)
Manually/Excel	Load document	5
D365	Load document	<1

Table 1 shows a comparison based on two methods: manual and D365. Creating a load document manually takes about five minutes, while the same job within D365 takes less than a minute.

The next analyzed data is the level of errors that can occur. The data are expressed in percentages, and 100 load documents created are taken into account.

Table 2. Data errors on 100 samples.

Method	Document name	Data errors
Manually/Excel	Load document	8%
D365	Load document	1%

Table 2 shows the level of error in percentages, depending on manual work and work through D365. Manual work is prone to errors of up to 8%, while D365 pushed that limit, reducing the error level to 1%.

In addition to the above items, the quality of the document itself, design, and readability of the data were also analyzed. Handwriting, of course, implies personal handwriting, so the readability of such documents is very difficult. The table shows the quality ratings, where a rating of 5 represents the best quality and 1 is very poor. Table 3 shows the visual quality rating of the document. Given that the manual method implies handwriting, the average rating of this document is two. Through D365, handwriting is completely eliminated, and this is replaced by printing documents. For this reason, the rating for the visual quality of such a document must be high.

Table 3. Visual quality of the document.

Method	Document name	Quality (1-5)
Manually/Excel	Load document	2
D365	Load document	5

Table 4 shows an analysis of the storage and archiving of such data. After a certain period of time, it is very important to be able to find documents quickly and easily. Manual archiving through files on the

computer and through archives is a slow and time-consuming process. Therefore, D365 introduces cloud archiving, where any document can be found quickly and easily.

Table 4. Data storage and archiving.

Method	Data storage	Spatiality (MB)	Data availability
Manually/Excel	Physically/Folders	1	Medium
D365	Cloud	0.1	High

Availability of data after manual work is more difficult due to the fact that they must be arranged within the archive. Finding such documents is slow and tedious. The data inside D365 is arranged in one place on the cloud, where access to such data is simple and fast. The space these documents occupy on the cloud is less than 0.1 megabytes.

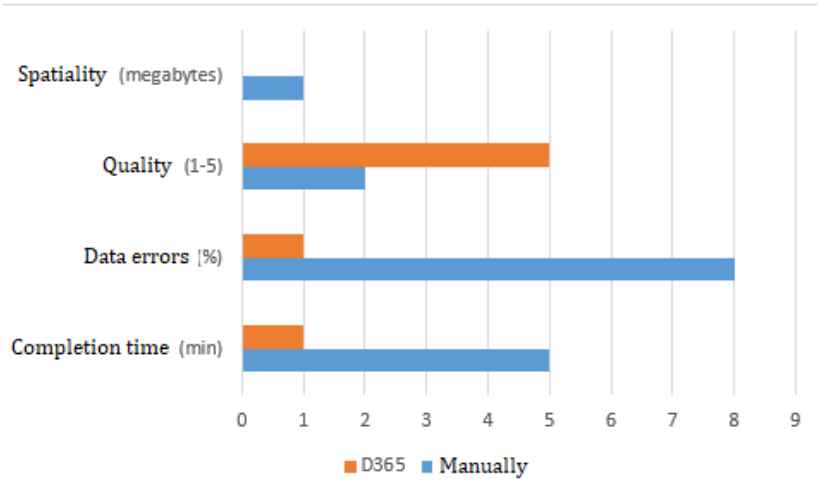

Figure 2. Analytical view of parameter comparison.

Figure 2 shows an analytical comparison of the parameters from the tables. The x-axis shows the numerical value, while the y-axis shows the different parameters in their units of measurement.

4. Conclusion

Within this paper, the creation of a document called a load document is analyzed through the implementation of the D365 and dox42 programs, for effective and fast documentation generation. D365 represents an ideal solution for this problem for creating dynamic and interactive documents, while dox42 allows for customized design..

Dox42 saves you time-consuming programming with SQL Server Reporting Services (SSRS), Electronic Reporting (ER), or tedious copy-and-paste. Eliminate complex report customizations with dox42 for Dynamics 365 for Finance and Operations to increase efficiency and return on investment (ROI) [6].

It also enables simplified creation and distribution of customer-specific documents, such as delivery notes, pre-printed labels, quotes, invoices, etc. It also enables the integration of dynamic tables and charts, images, barcodes, text modules, conditions, subtotals, and calculations [7,8].

The materials and methods used include a detailed description of how to create a user-friendly document, while the results show the advantages of using Microsoft Dynamics 365 together with dox42 compared to manual work, i.e. working through Microsoft Excel .

The diagram shows in detail how the advantages of working in these tools are reflected, where the reference measurement data were: time consumption, data errors, visual document quality, and data storage and archiving.

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Application of AI Methods for Cluster Analysis in Social Networks

Edina Karadžić[1] and Fatka Kulenović[2]

[1]Gymnasium "Bihać", Bihać, Bosnia and Herzegovina
[2]University of Bihać, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina

E-mail: edina.98@live.com

Abstract. The rapid development of social networks has led to the creation of complex digital ecosystems that generate vast amounts of data. Understanding the structure and dynamics of these networks is crucial for analyzing user behavior, identifying communities, and optimizing network interactions. This paper explores the application of clustering algorithms, including K-means, DBSCAN, and spectral clustering, in analyzing data collected from social networks. The experimental analysis evaluates the efficiency of these algorithms using metrics such as cluster homogeneity, separability, and robustness. The results indicate that DBSCAN demonstrates high precision in detecting dense subnetworks and anomalous users, while K-means achieves greater stability in structured datasets. The findings have broad applications in digital marketing, fake profile detection, user behavior modeling, and network influence analysis. This study provides deeper insights into the optimization of clustering methods and potential guidelines for future research in social network analysis.

Keywords. Clustering, social networks, machine learning, K-means, DBSCAN, spectral clustering, data analysis

1. Introduction

Social networks remain one of the fastest dynamic sources of data in the digital age, where millions of users from all parts of the world communicate and interact daily. Besides, they play an essential role in social relationship studies, user behavior, and information diffusion since the networks also serve as sources of communication and sharing personal experiences. The real volume of data that users of social media produce, in terms of textual posts, reactions, links, and all manner of digital interaction has increased dramatically over the years. This leads to the formation of highly complex, high-dimensional network structures that, in turn, call for sophisticated processing and analytical tools.

In most situations, the linear and structured data is too much for the common statistical techniques to handle. As described by [1], the data tends to be very nonlinear and unstructured, and dynamic. Therefore, one relies on machine learning, specifically unsupervised learning through clustering, to detect underlying groupings and structural patterns within the data. Clustering, as a method, identifies groups of items based on shared similarities. In simpler terms, items that belong to the same cluster are more similar to each other than to those from other clusters.

Community detection has proved important in social network analysis. It refers to the identification of node groups within a network with stronger interconnections amongst themselves than with the rest of the network. Therefore, it is possible to understand the network's internal structure, discover key participants, find anomalous users, and optimize network interactions. As posited by Bishop in the year 2006, the quality of patterns found is very greatly influenced by the clustering algorithm since different algorithms work on varied heuristics and assumptions on data distribution.

This paper compares three popular social network clustering algorithms- K-means, DBSCAN, and spectral clustering algorithms. K-means is a centroid-based algorithm which assumes spherical clusters and is sensitive to noise; DBSCAN uses data density as a core criterion for clustering and can detect noise

as well as irregular structures. Spectral clustering, on the other hand, helps detect complicated networks that use the eigenvalues of the graph Laplacian in conjunction with a similarity matrix [2].

The synthetic and real datasets used in this study for posterior analysis of the performance of the algorithms based on homogeneity, separability, and robustness metrics. The objective of the study is to bring out the strength and weakness in the application of varied methodologies, particularly in digital marketing and detecting fake profiles, analyzing user behavior and modeling network influence

2. Clustering in the Context of Social Networks

Social network analysis is basically the study of links between elements, where elements are shown as points on a chart. Grouping, which seeks to find user clusters with alike actions, may include "place in structure or link strength"—basically, sorting similar people into groups. This is very key for many uses like custom marketing, tips, finding influence and spotting fake accounts plus other odd actions.

Clustering is the unsupervised learning method of automatically finding natural structures in a data set when there is no pre-defined class label. A cluster, as per [5], refers to a collection of objects that are similar to one another in some properties but dissimilar to the objects in other clusters. Some of the methods for clustering are partitioning K-means, density-based DBSCAN, and graph-based spectral clustering.

2.1 K-means Algorithm

K-means is perhaps the most basic way of clustering. The main idea of the method is to allocate n observations to k clusters defined by the "centroid" of the observations, in such a way as to minimize the variance within clusters. The method works iteratively. At first, a set of k centroids is assumed; for every point in the space, find the nearest centroid and consider the point assigned to that cluster, then update the centroids to means of points in the groups. The process stops when the centroids no more change.

2.2 DBSCAN Algorithm

DBSCAN simply stands for what we earlier defined. It groups data by looking at how crowded or compacted different regions are. Rather than the number of clusters to form, DBSCAN needs two parameters to be set: ε (epsilon – the radius) and minPts (the number of points to be considered as neighbors). Points within the ε-neighborhood of a point are those found at a distance less than ε from that point; hence, the neighborhood of a point is defined by a distance metric and includes the point itself. The points that have at least minPts neighbors within the ε-radius are considered “Core” points; all others that do not have sufficient neighbors within this d*istance are therefore outliers.*

This method helps a lot when analyzing social networks. It can find odd users, such as bots or accounts used for spam, whose actions do not follow normal behavior. Another big reason the DBSCAN algorithm is good is that it can find clusters of any shape, which is true for most real-world uses [1].

2.3 Spectral Clustering

It is an approach that uses information on how close points are to one another on a graph: the Laplacian matrix of the graph and its eigenvalues and eigenvectors. These reduce the dimensions of the data to a lower level, and then one applies a standard algorithm like K-means.

An important feature that should be put across is the ability of spectral clustering to locate clusters within data where the shape is not assumed to be spherical or equal. When applied to social networks, it can separate well groups within communities where the links are not linear and are multidimensional. Though it might be accurate, this algorithm is not simple as well, which could be a problem when working with large amounts of data.

3. Methodology

This chapter gives a fine detail of the whole process of analyzing social network clustering using three most commonly applied algorithms: K-means, DBSCAN, and spectral clustering. Before going into the actual

implementation, data preparation and tools used and evaluation methods are explained to enable an objective assessment of the results.

3.1 Data Preparation and Description

The analysis used a synthetically generated dataset with four clearly defined clusters. The dataset was designed to simulate real user connection patterns in social networks, including possible overlaps and anomalies that frequently happen in such systems.

The dataset has 1,000 samples that are distributed across two spatial parameters. This will be easy and clear for visualization. Let these two parameters represent, for instance, the intensity and frequency of connections between users. Data is centered around centroids with a specified variance, which the random seed produces. It is paramount for testing algorithms on data that is controlled in a way but still realistic.

Use of the Python programming language which has a rich ecosystem of libraries for data processing and machine learning. Some of these libraries include scikit-learn (sklearn), numpy, matplotlib, and seaborn.

3.2 Implementation and Analysis of Clustering Algorithms

K-means is an algorithm, an approach to repeatedly optimizing the division of data into clusters, so that the sum of the squares within each cluster is minimized. More specifically, the algorithm starts by setting up k centroids—either randomly chosen or using some smart method—and then assigns all the data points to the nearest centroid. The process iteration continues until stability of the centroids is attained. The algorithm chosen is both efficient and scalable, hence commonly found in social network analysis for basic user segmentation. When the Silhouette value is about 0.65, it means that the groups are quite well distinguished and the algorithm performed suitably in segmenting by K-means. Having red plus signs as centroids of each group also aids in getting a visual percep*tion of where the clusters are.*

Table 1. Comparison of Algorithms and Results

Algorithm	Silhouette Score	Advantages	Limitations
K-means	~0.65	Fast, simple, efficient	The number of clusters must be known
DBSCAN	~0.55	Detects anomalies and noise	Parameter tuning is more difficult
Spectral Clustering	~0.63	Detects complex shapes	More complex, slower for large datasets

DBSCAN assumes clusters as areas of high density of observations separated by regions of low density. The shape of the cluster is defined by the distance function, whereas its neighborhood is determined by a local parameter ε. This method only requires the analyst to specify values for ε and the minimum number of points required to form a cluster. The points not falling within these neighborhood definitions are not considered as being part of any cluster and are labeled as noise or anomalies. In terms of social network analysis, it proves more than handy in detecting anomalies such as bot or spam accounts because their activities generally do not conform to regular patterns of interactions.

The spectral clustering algorithm computes the Laplacian of the graph via which the data is connected and then maps the data into a lower-dimensional space where standard clustering techniques like K-means can be applied. As a method based on graph and Laplacian, it helps detect clusters of various shapes and nonlinear trends and, thus, is mostly applied to problems in social network analysis where users are related through complex, often nonlinear relations. It is meant for datasets that are not easily separable linearly or which do not form any specific shape, a good representative being social network data. The qualitative Silhouette score is also good

.3.3 Evaluation and Comparison of Results

For all three methods, Silhouette analysis was used, which measures how similar an element is to its own cluster compared to other clusters. The values range from -1 to +1, where a higher value indicates better clustering quality.

A detailed implementation and analysis of three different algorithms show that the choice of method depends on the nature and goal of the social network analysis. For simple user segmentation, K-means is extremely convenient, while DBSCAN provides valuable insights into anomalies and unusual patterns. Spectral clustering offers flexibility for more complex networks with nonlinear relationships. This methodology lays a solid foundation for further application on real social network data where more complex structures and dynamic relationships among users are expected.

4. Results and Discussion

This section gives a close look at the results obtained from applying three different clustering algorithms: K-means, DBSCAN, and Spectral Clustering on the dataset simulating user activities on social networks. Here each data point stands for a user and has a set of features.

The K-means algorithm minimizes the variance within clusters, so the user must input the optimal number of clusters. This algorithm is best suited for clearly separated and well-distinguished dense data points; thus, it can be applicable to user segmentation based on defined behavior patterns. The algorithm often converges to obviously incorrect solutions. The weakness of the K-means method is that it is so very sensitive to the initial choice of cluster centers; users' average linkage tends to get stuck in one of the many minima, which is also a less stable solution. The other weakness of the method is that the number of clusters must be known a priori, something that is a rarity in social network analyses.

It considers the periphery of the facts. More formally, clusters are composed around a core site, while spare points are marked as not part of any cluster, or anomaly. This makes DBSCAN very useful for finding anomalous patterns of behavior; for example, in spotting bots or fake accounts that may not depart from the average behavior of a legitimate user. Key parameters for this algorithm are eps and min_samples. DBSCAN can find clusters of any shape, which often better reflects the true nature of interactions in a social network.

The spectral clustering approach performs a graph-based representation of data by factoring the Laplacian matrix, mapping data points into a lower-dimensional space where communities become separated. In more complex network structures with nonlinear relationships among users, it achieves results where standard methods fail. Its major drawback is that it is much slower than K-means and DBSCAN. The computation also does not scale practically to networks with more than a couple of 1000 vertices.

4.1 Graphical Representation

Results come up with scatter plots using color labels for each cluster, which offers a simple way to compare the algorithms' effectiveness in grouping data. The pictures clearly show that DBSCAN accurately isolates noise, while K-means forms more regular spherical clusters. Spectral clustering represents more complex shapes, especially important for real social networks.

DBSCAN operates with two primary parameters: eps, which is the maximum distance where points will be considered part of the same cluster, and min_samples, which is the minimum number of points needed to form a cluster. This parameter is very important because a large eps value can merge different clusters, while a small eps value can create too many small clusters or indicate too much noise.

It is fast and efficient for large data sets; hence, it is much more scalable for applications where there are many users. Since it must perform density analysis on every point, then it is slow. The spectral clustering method is not easily applicable to very large networks without some more work on it because it involves calculating similarity matrices and eigenvalues for each point. The spectral clustering method is not easily applicable to very very large networks without some more work on it because it involves calculating similarity matrices and eigenvalues.

Considering the results and visual representation, it can be said that K-means is for structured, spherical datasets with a clear number of clusters, but it does not react well to noise and the density of unevenness; it's not.

Figure 1. Input data before clustering.

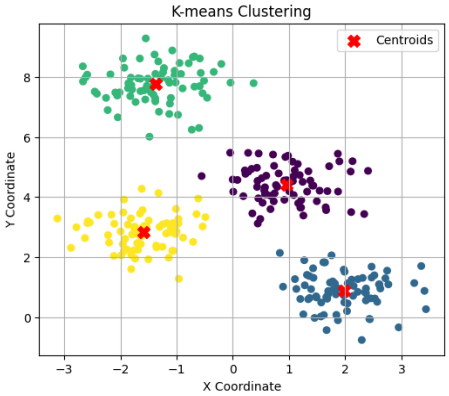

Figure 2. K-means Clustering.

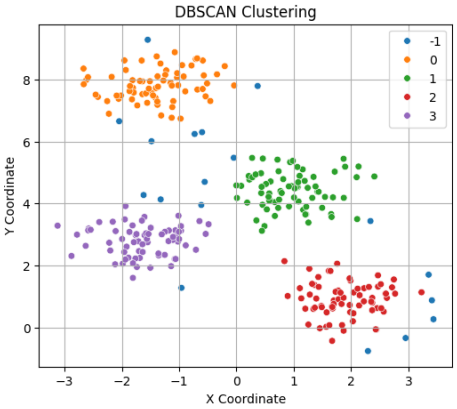

Figure 3. DBSCAN Clustering.

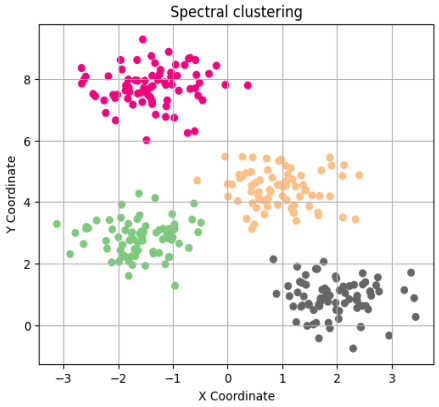

Figure 4. Spectral Clustering.

Considering the results and visual representation, it can be concluded that K-means is the perfect choice for structured, spherical data sets with a clear number of clusters, but it does not react well to noise and uneven density.

It works fine in locating clusters of odd shapes and spotting outliers, which is very handy in the actual setting of social networks where bots and false profiles crop up. Bright clustering gives better precision in finding complex shapes and groups but is much more computationally intensive and does not scale well with large datasets.

Standard metrics used to assess cluster quality were: silhouette – the current value showing how well clusters are separated; homogeneity – a measure of how consistent clusters are; and modularity – very important for network analysis. Results showed that spectral clustering achieves the highest silhouette score (0.75), a method known for its ability to detect complex structures. On the other hand, DBSCAN achieves the best modularity thanks to its ability to detect anomalies and noise.

4.2 Application in real cases

The results of applying clustering algorithms to real social network data should merely confirm their complementary advantages. DBSCAN was extremely successful in identifying bots and unwanted accounts on Twitter. This means that anomaly detection using this algorithm should be much more precise than when using other algorithms. In a similar setting, applied K-means to segment Facebook users for targeted

marketing. In another related work, spectral clustering was applied to the analysis of communities in collaborative scientific networks.

The nature and goal of the analysis should be aligned with the choice of algorithm. DBSCAN should be used for anomalies and noisy data. Choose K-means when the number of clusters is known for fast and clean segmentation. Spectral clustering serves well for the social network structures—both complex and nonlinear.

5. Conclusion

This paper compares different clustering algorithms applied to social network data for the purpose of detecting latent structures, features, and communities, i.e., users' groups. Results and the level to which the data can be understood are analyzed with the help of building a theoretical framework, its implementation, and checking the side effects of algorithm selection.

The K-means algorithm is rather efficient when clusters are easily identifiable and well separated. Since it is easy to implement and has low computational cost, it is appropriate for application in large datasets. Yet, high sensibility to initial values and the algorithm does not work with non-convex clusters restrict its application to more complicated networks.

DBSCAN allows for the clustering of based density, which is especially useful for detecting unusual nodes and behaviors, such as bots or isolated users. It can automatically determine the number of groups and ignore noise which is a great advantage though the proper selection of parameters ε and minPts requires further analysis.

Spectral clustering has proven useful when links between the points are not well brought out by real distances. The graph-based method enables the detection of communities based on the topological structure of the network, though its major problems in large datasets are very high computational cost and it depends on the dimensions of the matrix.

The study methodology involved data generation carried on the make_blobs function, a real dataset (Facebook Circles), and tools implemented in the Python programming language. The metrics for evaluation included the Silhouette Score, homogeneity, and modularity, serving to give a quantitative assessment of the quality of clusters as well as making the performance of different algorithms comparable

This work has triple value: theoretical, as it brings together modern approaches to unsupervised learning in graph processing; practical, as it provides concrete code and analyses that can be applied in real-world scenarios; and educational, as it can serve as a guide for researchers and educators who wish to introduce methods of artificial intelligence into network data analysis.

The algorithms under consideration provided great insights. In the future, this next work will use the Louvain method for community detection and the HDBSCAN algorithm for clustering with variable density, and also deep learning techniques will be integrated. All this, in principle, could make better the analysis of complex social networks and take it to a new level.

Future research should make it possible to work with more complex and multidimensional real-world networks and to use more algorithms such as the Louvain method. Also, analysis of temporal changes in the network structure plus supervised and unsupervised learning could be made to gain even more benefits. Further potential is in linking clustering with semantic analysis of communication content within the network, which would give a better understanding of the context of interpersonal interactions.

This research gives a good base for the ongoing building of tools and methods in the area of social network study using artificial intelligence.

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Similar Users in Social Networks Using Graph Theory in C++

Namira Krupić[1], Fatka Kulenović[2] and Šejla Jusić Gerzić[2]

[1]JU Mixed electrical engineering and woodworking secondary school, Bihac, BiH
[2]University of Bihać, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina

E-mail: krupicnamira@gmail.com

Abstract. Recommending similar users in social networks using graph theory is a challenge in the field of data analysis and optimization of user connections. Social networks can be modeled as graphs, where users are represented as nodes, and their interactions and connections as branches. Using graph theory, it is possible to analyze these connections to identify users with similar interests, activities, or behaviors. In this paper, C++ will be used as the main language for implementing the algorithms, as it provides high efficiency in processing large data and performing complex operations on graphs. Various methods for measuring user similarity, such as Jaccard index, SimRank, and Cosine similarity, are implemented in C++ using appropriate data structures such as set and unordered_map. Genetic algorithms, Collaborative Filtering and Content-based Filtering will be used to generate recommendations, and hybrid approaches combine these methods to achieve better accuracy. Additionally, algorithms for analyzing communities and centrality in graphs, such as PageRank and the Louvain method, will be implemented to improve the accuracy of recommendations based on the network structure. C++ allows for efficient handling of large graphs and fast analysis of user connections. The optimization results will be presented in the form of graphical representations, while the efficiency and accuracy of the system will be evaluated through various parameters. This approach will show how graph theory and C++ can be used to create an effective recommender system that improves the user experience in social networks.

Keywords: Social Networks, Users, Graph Theory, Programming language C++

1. Introduction

In the age of technology and social networks, connecting with friends who share similar interests, activities, or behaviors presents a challenge that can be addressed using graph theory—specifically, through directed graphs (for recommending "friends of friends") and undirected graphs (where nodes represent users and edges represent friendships). The C++ programming language, due to its execution speed, memory management, and the use of STL libraries—which provide optimized data structures such as vectors—simplifies the implementation of graphs. Object-oriented programming enables the creation of classes and objects, such as the UndirectedGraph class. The goal of this work is to use C++ to apply directed and undirected graphs, via adjacency lists, to solve the problem of friend recommendations on social networks based on mutual friends, similarities, and interests. Here, nodes represent users, and connections between nodes represent friendships between those users.

2. Directed Graph Using Adjacency Lists in C++

In graph theory, a directed graph is an ordered pair consisting of nodes and directed edges. In these graphs, each edge is an ordered pair, indicating a connection from one node to another. Directed graphs provide a solution for social network users because edges have direction — for example, "from node A to node B," represented as an ordered pair *(u,v)*. To better understand the use of directed graphs in social networks, we first review basic definitions. A directed graph is an ordered pair [1]:

$$G = (V, E)$$

where:

V - is a set of vertices (nodes),

E - is a set of ordered edge pairs (also called arrows).

As shown in Figure 1:

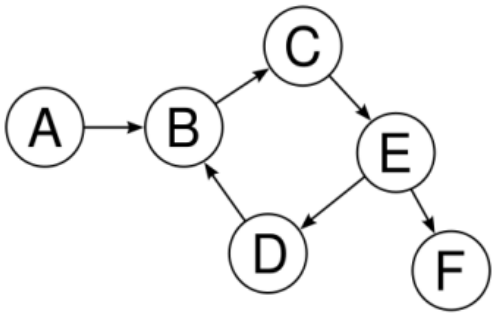

Figure 1. Directed Graph

In C++, graphs are modeled using adjacency lists or matrices. For friend recommendations on social networks, we use adjacency lists, where each node stores its neighboring nodes, allowing easy traversal. .

The adjacency list for each node $x \epsilon V$ connects all nodes *v* to which *u* has an edge. Mathematically, the adjacency list for a node u is defined as:

$$G(u) = \{ u \in V \mid (u, v)\, u \in E \}$$

This means all nodes v that have an edge from u.

To implement a directed graph in C++, we use the class *DirectedGraph*, which takes a list of edges as pairs. The adjacency list uses fast indexing, where an *int* key represents a node, and a vector stores the list of nodes it points to. In this case, the constructor takes a list of edges, where each edge is represented as a pair of integers, i.e. it directs an edge from *from* to *to*. The *for* loop goes through each edge in the vector edges, where *edge.first* represents the starting node, and *edge.second* represents the ending node, as shown in Figure 2.

```
class DirectedGraph{
    private:
        unordered_map<int, vector<int>> adjList;

    public:
        DirectedGraph(const vector<pair<int,int>>& edges){
            for(const auto& edge: edges){
                addEdge(edge.first, edge.second);
            }
        }
```

Figure 2. Code from the DirectedGraph Class

To add a directed edge from u to v we use *void addEdge(int u, int v)*, which belongs to the class *DirectedGraph*. We use *int u,* as the starting node, and the end node is represented as *int v*. To store all the neighbors of each node, an adjacency list, *adjList*, is used, presented in Figure 3.

```
void addEdge(int u, int v){
    adjList[u].push_back(v); //adds a one-way connection from the direction of node "u" to "v"
}
```

Figure 3. Function *void addEdge(int u, int v)*

To print a graph in the form of an adjacency list, we use the function *void printGraph()*, where each link has its own direction, 1→2, but not 2→1, presented in Figure 4.

```
void printGraph() const{ //print graph in adjacency list form
    for(const auto&[node, neighbors] : adjList){
        cout << node << " -> ";
        for(int neighbor : neighbors){
            cout << neighbor << " ";
        }
        cout<<endl;
    }
```

Figure 4. Printing a graph in the form of an adjacency list

In addition to friendly requirements, this directed graph is ideal for modeling traffic directions and data flows, shown in Figure 5.

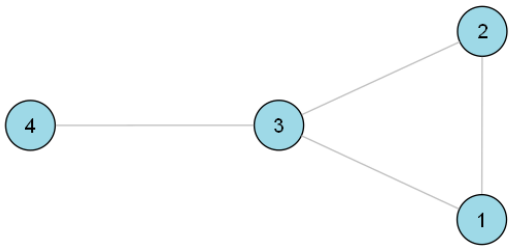

Figure 5. Printing a graph in the form of an adjacency list

2.1. Directed graph for social networks in programming language C++ user recommendation based on mutual friends

To find friends from friends, which the user does not yet have on social networks, in the C++ programming language this is realized using the class *DirectedGraph(const vector<pair<int,int>>& edges)* and a constructor that receives a list of pairs of nodes *(u,v)* and adds each link via the *addEdge()* function, which adds an oral link between the node *(u,v)*, if it happens that *v* not yet in the map, it is added with an empty vector ([]). Using the function *recommend(int u, int k)* friends of the social network user *u* are recommended, based on mutual friends, to user *k* , whom he would like to add, in a way that takes his direct friends, searches their friends, skips already existing connections, counts how many mutual friends he has and sorts by the number of mutual friends and returns under *k*, as shown in Figure 6.

Taking 33 users (nodes), among which there are directed links representing follower or friend relationships from one side to the other, in the programming language C++, a complex social network is modeled, where the links are directed and represent follower relationships. Such a graph allows for network analysis and recommendations to users based on their existing connections and the connections of their friends, which can help in discovering new relevant contacts, as shown in Figure 7

```
class DirectedGraph{
    private:
        unordered_map<int, vector<int>> adjList;

    public:
        DirectedGraph(const vector<pair<int,int>>& edges){
            for(const auto& edge: edges){
                addEdge(edge.first, edge.second);
            }
        }

        void addEdge(int u, int v){
            adjList[u].push_back(v);
            if (!adjList.count(v)) adjList[v] = {};
        }

        void printGraph() const{ //ispis grafa u obliku adjacency liste
            for(const auto&[node, neighbors] : adjList){
                cout << node << " -> ";
                for(int neighbor : neighbors){
                    cout << neighbor << " ";
                }
                cout<<endl;
            }
        }

        vector<pair<int,int>> recommend(int u, int k) const{
            if (!adjList.count(u)) return {};

            unordered_set<int> directFriends(adjList.at(u).begin(), adjList.at(u).end());
            unordered_map<int,int> countMap;

            for(int friendNode : directFriends){
                for(int fof : adjList.at(friendNode)){
                    if(fof == u || directFriends.count(fof)) continue;
                    countMap[fof]++;
                }
            }
```

Figure 6. DirectedGraph class representation

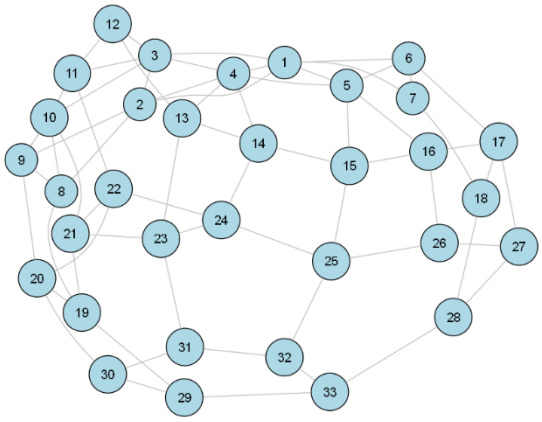

Figure 7. Graphical representation of direct connection in the C++ programming language

Directed graphs are used when the relationship is one-sided or not necessarily reciprocated and these are examples of social networks such as following on Twitter, Instagram, YouTube. The advantages of a directed graph are that it provides more information, enables information flows, popularity and impact analysis. On the other hand, the disadvantages of using directed graphs are that they require more complex algorithms and greater computing power, especially for large networks, as well as more difficult visualization of graphs with many nodes and connections that can be complex for graphical representation and interpretation.

2.2. User recommendation based on mutual friends on social networks using unordered graph

Unordered graphs represent a structure in which the connections between nodes (or vertices) are bidirectional. This means that if there is a connection between node A and node B, it is valid in both directions, A is connected to B and B is connected to A. In the C++ programming language, unordered graphs are usually represented by [2]:

- Adjacency list: map<int, vector<int>>
- Adjacency matrix: symmetric matrix

The advantages of adjacency list are efficient for sparse graphs (graphs with few connections), less memory than adjacency matrix, and easy to iterate through the neighbors of a node. With the *addEdge(u,v)* function in the C++ programming language, we create a symbolic link, if u is a friend of v, then v is also a friend of u, written in the code as in Figure 8.

```
void addEdge(int u, int v){
    adjList[u].push_back(v);
    adjList[v].push_back(u);
}
```

Figure 8. Function *addEdge(u,v)*

Through a practical example of a network graph of 33 users, in the programming language C++, we can show how to find and suggest potential new friends, i.e. users who are not directly related to the user, but have mutual friends with him. The graph is stored as an adjacency list *(unordered_map<int, vector<int>> adjList),* which is an efficient structure for storing connections in sparse graphs. The *addEdge(u, v)* function connects two users with a two-way (undirected) connection. The function *recommend(u, k)* searches for users who are not direct friends of user u, but are friends of a friend (FoF - friend of a friend). Those who have the most friends in common with the user in are recommended, and mostly to them. The *exportAndOpen()* function automatically creates a *.dot* file to display the graph using *Graphviz* shown [3] in Figure 9.

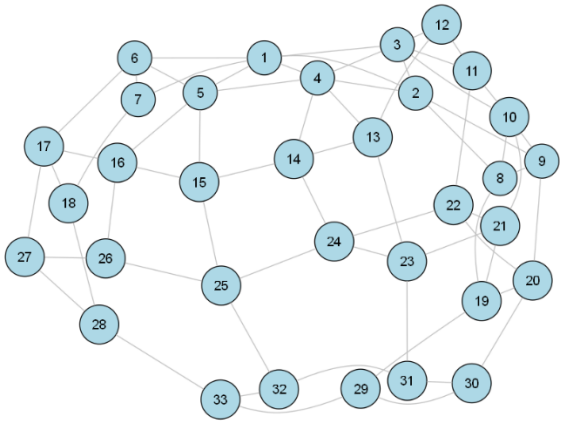

Figure 9. Graphical representation of an unordered graph in the C++ programming language for 33 users

4. User recommendation based on mutual friends on social networks using an undirected graph

In order to create a relationship between two users in both directions on social networks, graph theory, an undirected graph, is used to create mutual friendship, i.e. for user 1 to reach user 2 and likewise user 2 to user 1. Based on an undirected graph $\mathrm{G} = (\mathrm{V}, \mathrm{E})$, where V is a set whose elements are called nodes, and $E \subseteq \{(u,v)|u,v \in V, u \neq v\}$ is a set of pairs of edges. Each edge (u,v) means that there is a connection between nodes u i v [3].

In the C++ programming language, the undirected graph method, using the *UndirectedGraph* class, which stores the graph as an adjacency list, *unordered_map<int, vector<int>> adjList*. Algorithm for user *recommendation* and *main()* function, we enable user recommendation based on mutual friends. If we apply the mathematical definition in the program code, the graph G is generated as:

$$\mathrm{G} = (\mathrm{V}, \mathrm{E})$$

if we know that V is a set of nodes, in this case users:

$$V = \{1,2,3,4,5, \dots ,33\}$$

E represents unordered pairs of users representing friendships:

$$E = \{(1,2), (1,3), (2,3), (3,10), (4,12) \dots , (33,29)\}$$

4.1. Jaccard similarity for friend recommendation

Jaccard metric - measures the dissimilarity between sets, and is obtained by dividing the difference between the union sizes and the intersection of the two sets by the union size [4].

$$\mathrm{J}(A, B) = \mid A \cap B \mid / \mid A \cup B \mid$$

If we assume that A is the set of friends of user u, and B is the set of friends to recommend, then |A∪B| is the total number of different users of both friends, and |A∩B| is the number of mutual friends, we can use Jaccard similarity to recommend friends on social networks. In this case, in the programming language C++, we first take the user's friends, after that we generate candidates, as shown in Figure 10:

```
for(int friendNode : userFriends){
    for(int fof : adjList.at(friendNode)){
        if(fof == u || userFriends.count(fof)) continue;
        candidates.insert(fof);
    }
}
```

Figure 10. Friend search

The structure of the graph is maintained via an adjacency list *(adjList)*, implemented using *unordered_map<int, vector<int>>*, which allows fast addition and search of connected users. In addition to the structure of friendships, each user's interests are recorded through a set of strings *(unordered_set<string>)*, which contain terms like "music", "football", "gaming", etc. In this way, an additional dimension of the user profile is made possible, outside of the network structure itself. To calculate the degree of social similarity between two users - a target user and a potential recommendation candidate, *intersectionSize* calculates the number of mutual friends between the user and the candidate. Each friend that appears with both users increases the value of the intersection. Union of friend sets *unionSize* represents the total number of distinct friends that both users have together. This algorithm uses a realistic social principle: the more mutual friends two people have, the more likely the system will recommend them to each other. Thus, the recommendations are not based randomly, but have a basis in the real structure of the network and the possibility for these users to get to know each other, the Jaccard similarity of C++ is shown in Figure 11:

```
int intersectionSize = 0;
for(int f:userFriends){
    if(candidateFriends.count(f)) intersectionSize++;
}
int unionSize = userFriends.size() + candidateFriends.size() - intersectionSize;
double socialSimilarity = (intersectionSize == 0) ? 0.0 : (double)intersectionSize / unionSize;
```

Figure 11. Jaccard similarity shown in the C++ programming language

3.1. Cosine similarity for friend recommendation

For recommending friends between social network users, in the C++ programming language, it is possible to use cosine similarity. The optimal solution for recommending friends, this method is used because of its measurability for recommendation, which gives a value between minus one and one.
Mathematically, for two vectors A and B, cosine similarity is defined as [4]:

$$\text{CosineSimilarity}(A, B) = \frac{A \times B}{||A|| \times ||B||}$$

If we take two sets of users (friends) and define that A is a friend of user *u*, and B is a friend of user *v*, using the *UndirectedGraph* class and the *adjList* map, which stores the vectors of his friends for each node, and by adding the addEdge function between the two users, with a link in both directions, shown in Figure 12:

```
void addEdge(int u, int v){
    adjList[u].push_back(v);
    adjList[v].push_back(u);
}
```

Figure 12. Function *addEdge(u,v)*

The focus of the program is the *recommend* method, the main purpose of which is to find users who are not already friends with a given user, but share mutual friends, and therefore have the potential to be recommended. The part of the code that plays a key role in the estimation of user similarity is based on the cosine formula, where *intersectionSize* counts the common friends between the user and the candidate, while *unionSize* represents the total number of different friends they have together - it is calculated as the sum of the sizes of both sets minus the number of common members, shown in Figure 13:

```
    int intersectionSize = 0;
    for(int f:userFriends){
        if(candidateFriends.count(f)) intersectionSize++;
    }

    int unionSize = userFriends.size() + candidateFriends.size() - intersectionSize;

    double cosine = (intersectionSize == 0) ? 0.0 : (double)intersectionSize / unionSize;

    similarityMap[candidate] = cosine;
}
```

Figure 13. The cosine formula shown in the C++ programming language

To display a graphical visualization of the graph, *exportAndOpen()* and the *Graphviz* library are used, and the printout based on the requested data is shown in Figure 14.

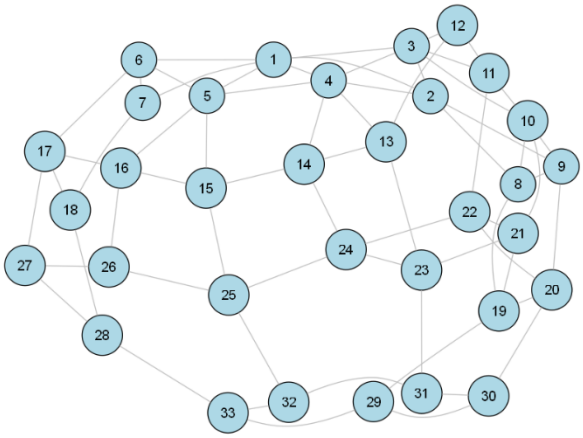

Figure 14. Graphical representation of cosine similarity based on entered data

5. An undirected graph for finding social network friends with shared interests and social similarity

For social similarity and common interests between two users, Jaccard similarity is used, due to the undirected friendship graph, the *UndirectedGraph* class should contain *adjList*, which stores connections and *userInterests*, a map of interests of users and the users themselves. The main algorithm *recommend(int u, int k)* needs to collect all the user's friends, find candidates, calculate the similarity for each candidate and interest similarity, in order to get the total combined similarity: Mathematically:
Social similarity:

$$\text{Social}(u, c) = \frac{|Friends(u) \cap Friends(c)|}{|Friends(u) \cup Friends(c)|} \quad (1)$$

Similarity of interest:

$$\textbf{Interest}(\boldsymbol{u}, \boldsymbol{c}) = \frac{|\textbf{Interests}(\boldsymbol{u}) \cap \textbf{Interests}(\boldsymbol{c})|}{|\textbf{Interests}(\boldsymbol{u}) \cup \textbf{Interests}(\boldsymbol{c})|} \quad (2)$$

Combined similarity:

$$\text{FinalScore}(u, c) = \alpha \times Social(u, c) + \beta \times Interest(u, c) \quad (3)$$

In the C++ code, the social similarity (1) between users and referral candidates is determined using Jaccard similarity over their friend sets. That part of the code is located inside the *recommend* function, and is shown in Figure 16.

```
int intersectionSize = 0;
for(int f : userFriends){
    if(candidateFriends.count(f)) intersectionSize++;
}

int unionSize = userFriends.size() + candidateFriends.size() - intersectionSize;

double socialSimilarity = (intersectionSize == 0) ? 0.0 : (double)intersectionSize / unionSize;
```

Figure 16. Social similarity in the C++ programming language

Interest similarity (2) is calculated within the recommend function, immediately after social similarity is calculated, as presented in Figure 17.

```
double interestScore = 0.0;
if (userInterests.count(u) && userInterests.count(candidate)) {
    const unordered_set<string>& interestsU = userInterests.at(u);
    const unordered_set<string>& interestsC = userInterests.at(candidate);

    int common = 0;
    for (const string& s : interestsU)
        if (interestsC.count(s)) common++;

    int unionSize = interestsU.size() + interestsC.size() - common;
    interestScore = (unionSize > 0) ? (double)common / unionSize : 0.0;
}
```

Figure 17. Interest similarity in the C++ programming language

To calculate the combined similarity (3) we take *socialSimilarity*, which measures similarity based on mutual friends (social similarity) and *interestScore*, which measures similarity based on common interests (interest similarity). As weights, we take the numbers 0.7 and 0.3, which determine how important each type of similarity is in the overall rating of the recommendation, shown in Figure 18.

```
double finalScore = 0.7 * socialSimilarity + 0.3 * interestScore;
similarityMap[candidate] = finalScore;
```

Figure 18. Combined similarity in the C++ programming language

Combined similarity, taking two criteria, social and interest similarity, in the C++ programming language, user recommendations are generated that are most relevant to the given user, without already being his friends. This approach significantly improves the quality of recommendations because it does not rely exclusively on friendships, but also includes the user's interest affinities. Undirected graphs are used when the relationship is bidirectional and mutually confirmed. Examples of such links are on social networks such as Facebook or connections on LinkedIn if accepted by both parties. These types of graphs also have certain modeling advantages and disadvantages. The advantages of an undirected graph are that it has a simpler structure that is useful for networks of close friends and communities. The main disadvantages are the loss of information about the direction of the connection, since undirected graphs do not distinguish who initiated the connection, which can be important in the analysis of user behavior, as well as the fact that they cannot be used to disseminate information and measure the impact on users.

6. Conclusion

Social networks in today's technology are the basic means of communication, and friend recommendations are based on various interests, common connections and social similarity. This paper shows how graph theory (directed or undirected graph) can be effectively used in the programming language C++, for social networks, to recommend friends based on mutual friends, interests or social similarity. The C++ programming language, due to the speed of execution, memory management and the use of STL libraries, offers optimized data structures, such as vectors, which in this way facilitate the implementation of graphs. The result of the work is the development of a system to solve the problem of social networks recommending friends based on mutual friends or similarities and interests. In C++ programming, an undirected graph is easier to implement because each connection between nodes is recorded in both directions, which makes search and modification operations easier. On the other hand, a directed graph records connections in only one direction, so the implementation is somewhat more complex, but it provides a more accurate model for situations where the direction of the connection matters. The

advantages of an undirected graph in C++ are that it is simpler to implement and maintain, efficient for problems where connections have no direction (social networks, connected sets), and less complexity in iteration and updating, while a directed graph in C++ allows us to precisely model relationships with direction and is better for analyses where the direction of the connection matters.

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Correlation between computational and electronic body composition analysis

Azira Hrnjica, Sena Našić, Ekrem Pehlić, Milica Mirković and Lejla Hodžić

University of Bihać, Faculty of Health Studies, Bosnia and Herzegovina

E-mail: azira.hrnjica@unbi.ba

Abstract. Obesity is defined as an excessive amount of body fat in relation to lean body mass. Body mass index (BMI) is used to define the medical standard of overnutrition in many countries, and an increased BMI value is widely used to determine obesity. There are individuals with a normal body weight according to BMI and a high percentage of body fat, which indicates a high degree of metabolic dysregulation. When assessing the risk of developing diseases related to obesity, it is important to take into account some other measures that indicate the distribution of fat tissue in the body. This study examine the relationship between the results of the BMI obtained by calculation and the results obtained by an electronic scale that works on the basis of bioelectrical impedance and gives results on the distribution of adipose tissue in the body. The body composition of 24 female subjects, age between 19 and 29 years, was analyzed with the TANITA precision electronic scale. In this way, data were obtained on the distribution of adipose tissue in the body with the proportion of visceral fat, and the percentage of water in the body. The correlation of these results with the results of the BMI of the subjects obtained by computational means was examined. Results: According to the results of BMI, 29% of respondents belong to the pre-obesity category, while the results obtained by electronic scales indicate that 33% of respondents have an excessive amount of adipose tissue, which is statistically significant in detecting the risk of chronic non-communicable diseases (NCDs) in the general population. Furthermore, 37.5% of respondents had high-fat news between 3 and 6%. It can be concluded that with a precise electronic scale, it is possible to detect metabolic dysregulation in people of normal body weight. Therefore, it is recommended to use an electronic scale in detecting the risk of NCDs because it has its advantages. It is recommended, in addition to regular BMI monitoring, at least occasional analysis with an electronic precision scale to get a more complete insight into body composition.

1. Introduction

Replace Malnutrition is described by the definition of the European Society for Clinical Nutrition and Metabolism (ESPEN) as a state of undernutrition or obesity. Malnutrition is not the same as being underweight, as malnutrition may be present in obese individuals. Body mass index (BMI) is used to define the medical standard of obesity in many countries, and an increased value of BMI is widely used to determine obesity [1]. However, taller and/or more muscular individuals generally have a higher BMI, although their body fat percentage is relatively low. On the other hand, there are individuals with a normal body weight according to BMI, but a high percentage of body fat, indicating a high degree of metabolic dysregulation. This phenomen is defined as obesity with a normal weight. The standard BMI calculation method cannot detect such cases.

Therefore, it is necessary to improve and apply technological development in all aspects of life, including health care, early detection and prevention of obesity, and obesity with a normal weight. This paper presents an example of applying the TANITA BC 350 precision scale, or body composition analyzer, to detect obesity in people with a normal weight according to the BMI index. The importance of applying technologies is emphasized by comparing these two methods of determining obesity in the population.

2. Theory

2.1 Obesity and obesity with normal weight

Obesity is a chronic disease characterized by excessive fat deposits. Obesity increases the risk of cardiovascular disease, type 2 diabetes, bone and reproductive organ diseases, and certain types of cancer. Obesity affects the quality of life, sleep, and activity levels [2]. Obesity is strongly associated with obstructive

sleep apnea (OSA). At least 60% of OSA patients are obese. It is thought that adipose tissue dysfunction may contribute to OSA-induced pathogenesis. The increased number and size of adipocytes in obesity represent an endocrine tissue that secretes many hormones, proteins, and cytokines [3]. Therefore, obesity is a complex disease that increases the risk of other diseases. Worldwide, adult obesity has more than doubled since 1990, and adolescent obesity has quadrupled [2]. According to the WHO data, obesity rates in the Eastern Mediterranean region have been on the rise in recent decades. As of 2023, approximately 60% of adults in some countries in the region were overweight or obese [4].

According to the WHO report, in 2022, 43% of adults aged 18 and over were overweight (2.5 billion adults), and 16% of them were living with obesity. This means that 1 in 8 people in the world struggles with obesity. By 2030, it is estimated that 1 billion people globally will be obese. Data from 2022 shows that 51% of the European Union population over 16 years of age is overweight, while 17% is obese [5]. The data for Bosnia and Herzegovina is even more devastating than the previously mentioned global and European data. In 2025, as many as 59% of adults in Bosnia and Herzegovina had a high body mass index (BMI) (above 25kg/m2), while 23% of adults lived with obesity. The Bosnia and Herzegovinas data also shows that, according to gender distribution, being overweight is significantly more prevalent in the female population [6]. Taking action against obesity will help reduce the global burden of other chronic diseases, including diabetes, cardiovascular disease, and cancer. The diagnosis of overweight and obesity is determined by calculating the body mass index (BMI): person weight (kg)/person height (m^2). Additional measurements, such as waist circumference, can help in the diagnosis of obesity [2].

The cluster of abdominal obesity, systemic hypertension, insulin resistance, and dyslipidemia is called metabolic syndrome, and it is associated with an increased risk of cardiovascular disease and all-cause mortality. A key component of metabolic syndrome is abdominal adiposity [7].

2.2 Quetelet's Index

Adolphe Quetelet developed body mass index (BMI) during the 19th century. BMI is a good indicator of adiposity and problems associated with being overweight. According to the World Health Organization, adults over the age of 20, according to BMI, fall into one of the following categories shown in Table 1.

Table 1. Nutritive status according to BMI index

BMI	Nutritional status
below 18.5	Underweight
18.5 – 24.9	Normal weight
25.0 – 29.9	Pre-obesity
30.0–34.9	Obesity class I
35.0–39.9	Obesity class II
above 40	Obesity class III

This measure is not perfect because it only depends on height and weight and does not consider different levels of obesity based on age, physical activity level, and gender. Therefore, a BMI, in some cases, overestimates adiposity, and in others, underestimates it. That is why it is important to consider other measures such as waist circumference. Finding a relationship between waist circumference and health risks is not easy. Therefore, scientifically based techniques should be used [8]. At the population level, BMI is the most commonly used tool for correlating the risk of health problems with weight. Individuals with a normal body weight according to the BMI and a high percentage of body fat show a high degree of metabolic dysregulation. This phenomenon, defined as normal weight obesity, is associated with a significantly higher risk of developing metabolic syndrome, cardiometabolic dysfunction, and higher mortality. BMI as a measure of body fat has become popular and widely used due to its simplicity and validation in multiple

epidemiological studies. Surprisingly, although obesity is defined as excess fat, there is no consensus on how to define obesity using fat mass or body fat percentage calculations, except for the effort of the American Society of Endocrinologists who defined obesity as a body fat percentage of > 35% in women and > 25% in men [9].

2.3 Bioelectric impedance method

Bioelectrical impedance detection technology uses the electrical properties of biological cells and tissues to obtain relevant biomedical information. It has attracted significant attention in the biological detection field due to its accessibility, convenience and non-invasiveness.

Bioelectric impedance is a technique of analyzing the internal structure and function of biological organisms by measuring their impedance to electric currents. The basic principle of operation of the bioelectrical impedance analyzer (BIA) is based on Ohm's law, where impedance Z is defined as the ratio of voltage V and current I:

$$Z = \frac{V}{I}$$

Impedance Z is a complex quantity and can be expressed as:

$$Z = R + jX$$

where is :

R – resistance ; represents the resistance of body tissues to the passage of electric current

X – reactance, represents the capacitive and inductive effects of cells and tissues

j – imaginary unit

BIA uses total body impedance measurement to estimate body water volume (Total Body Water, TBW). The body is considered a set of conductive and non-conductive elements; water conducts electricity well, while fatty tissue provides greater resistance. For the calculation of body water volume, the following formula is used, which relates impedance to body height H and specific tissue resistance (specific resistance) ρ:

$$V = \rho \times \frac{H^2}{R}$$

where is:

V – body water volume (TBW)

H^2– height-squared ; in a person of higher height the current passes through a longer path. Therefore the volume of water is estimated as proportional to the square of the height.

R – measured body resistance

ρ – specific tissue resistance (a constant that varies depending on the tissue and current frequency). Into account is taken constant tissue resistance. Constant tissue resistance refers to average standardized values of specific resistance for different tissues. These values are used in formulas and they are approximate, empirically determined values. These values may differ depending on the method and device.

Based on the volume of body water (TBW), lean body mass, or Fat-Free Mass (FFM) is calculated. The assumption is made that there is about 73.3% water in the total amount of lean body mass, and it is calculated according to the formula:

$$FFM = TWB/0.733$$

Finally, the body fat mass (Fat Mass, FM) is calculated as the difference between the total body mass (TBM) and the lean body mass (Fat-Free Mass, FFM):

$$FM = TBM - FFM$$ [10,11].

Advanced BIA devices are based on segmental analysis: they measure the impedance for each body segment (arms, legs, trunk) separately, increasing accuracy. The combination of impedance, height and body weight measurements using the above formula allows BIA analyzers to accurately assess body composition, including fat, muscle mass and total body water [11].

Tissues with different compositions and physical structures exhibit different bioelectrical impedance spectra. These characteristics can help in the medical diagnosis of diseases and treatments [12]. Magnetic resonance imaging (MRI) and computed tomography (CT) can accurately measure body composition and the accumulation and distribution of visceral adipose tissue, but their high cost limits their clinical usage.

Bioelectrical impedance analysis (BIA) has become popular because it is a safe, rapid, radiation-free, noninvasive, simple, portable, and cheaper method for assessing body composition and visceral adipose tissue surface area. Previous studies have reported good concordance between visceral adipose tissue assessed by BIA and assessed by CT/MRI [7]. BIA measures body composition by estimating total body water and body fat based on the body's resistance to a small electrical current using a 2-compartment model and predictive equations [13].

TANITA BC -351, a body composition analyzer, is an Innerscan line model (device for complete internal scanning of the body composition). The measurement resolution is 0.1%/50 g. The TANITA company developed the TANITA body composition analyzer/monitor based on the BIA (Bioelectrical Impedance Analysis) method. The method principle is as follows: a very weak, safe electrical signal of about 50 kHz is sent through the body. Electrical energy passes easily through the fluids contained in muscle tissue, but faces resistance when passing through fat tissue, and this is called bioelectrical impedance. Body composition analyzers detect bioelectrical impedance with a high accuracy rate. The TANITA company has created a large database of independent research and expert data that confirms the precision of the TANITA analyzer. The TANITA body composition analyzer for home use is also based on the BIA method, which is certified by the gold standards DEXA (Dual Energy X-Ray Absorptiometry) and UWW (Under Water Weighting). TANITA is the world's leading manufacturer of high-precision electronic scales. The TANITA body composition analyzer complies with international quality standards, such as the Medical Devices Directive 93/42/EEC and the European Non-Automatic Weighing Instruments Directive 90/384/EEC. The TANITA body composition analyzer can provide the following data:

- The total body fat index gives the percentage ratio of fat tissue to the total body weight. A high level of total body fat worsens health, however, a very low percentage of total body fat is a sign of disease (dystrophy, anorexia).
- Visceral fat level: The fat that surrounds the internal organs serves as a protective cushion against mechanical influences. However, an excess of visceral fat leads to the development of cardiovascular diseases and diabetes.
- Muscle mass summarizes the mass of muscle tissue in the body, including the skeletal and smooth muscles of internal organs, and the water contained in them [14].

3. Methods

This research included 24 female participants aged between 19 and 26 years. A precise electronic scale, TANITA BC 351, was used, which analyzes body composition and measures the index of total body fat, visceral fat level, and percentage of water. The participants' height was measured, and they stood barefoot on the scales. The scale results were observed, manually written down, and used for further investigation. In this way, data were obtained on the distribution of adipose tissue in the body, with the proportion of visceral fat, and the percentage of water in the body. The correlation of these results with the results of the body mass index (BMI) of the subjects obtained by computational means was examined.

4. Results

Based on the calculated BMI, the subjects were classified into the appropriate category as shown in Table 2.

Tabela 2. Nutritional status of the subjects according to BMI

BMI	Number of respondents	(%)	Nutritional status
below 18.5	1	(4 %)	Underweight
18.5 – 24.9	16	(67 %)	Normal weight

25.0 – 29.9	7	(**29 %**)	Pre-obesity
30.0–34.9	/		Obesity class I
35.0–39.9	/		Obesity class II
above 40	/		Obesity class III

The results of body fat measurement in TANITA BC 351 subjects are shown in Figure 1.

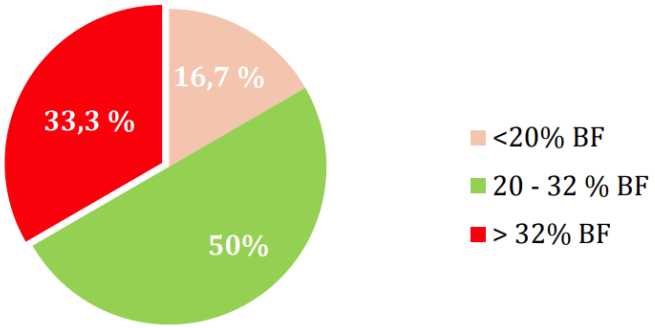

Figure 1. Categories of subjects by body fat percentage measured with the TANITA BC 351 analyzer, *BF – body fat*

The levels of visceral fat in the subjects are shown in Figure 2.

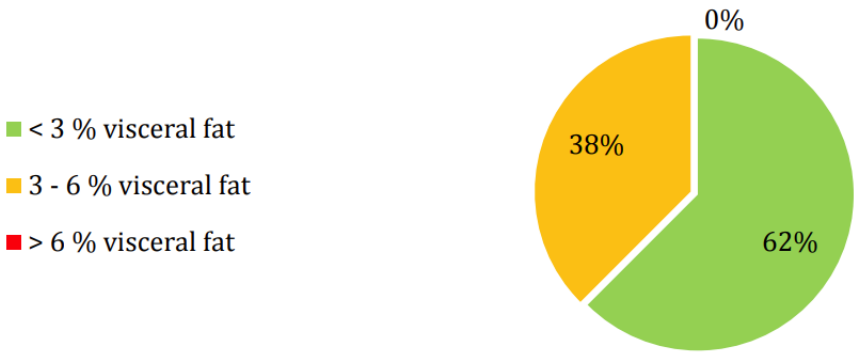

Figure 2. The percentage of visceral fat in the test subjects measured with the TANITA BC 351 analyzer

5. Discusion

Using the Quetelet index, 29% of the participants were detected to have an increased risk of developing chronic non-communicable diseases because they were found to be overweight, while using TANITA BC 351, 33% of the respondents were detected to have an increased risk of developing chronic non-communicable diseases due to an increased body fat percentage above 32%. Furthermore, as many as 38% of the participants were detected to have a slightly higher proportion of visceral fat, which increases the risk of developing non-communicable diseases (NCDs). Hidden obesity, or obesity with normal weight, was detected by this technology application.

Although there are varying guidelines and disagreements about what amount of body fat in a person poses a health risk, many researchers believe that a body fat percentage of 32% or over for women may be dangerously high. The opinions are based on data collected from the National Health and Nutrition Examination Survey and supported by the American Council on Exercise, providing scientifically validated thresholds commonly used in research and clinical practice [15].

Based on research, this paper recommends that the bioelectrical impedance method in the form of a body composition analyzer can be used for national strategies to prevent and reduce obesity in the general population. TANITA body composition analyzers are shown to be effective, simple, and quick to use. For the measures taken to have a timely and long-term effect, they should start being used on children. According to the study conducted in Hong Kong in 2009, whose goal was to establish reference standards for the percentage of body fat in Chinese children and in which the bioelectrical impedance method was used on a sample of 14,842 children [16], it is recommended that this study also gets conducted in Bosnia and Herzegovina to establish a national reference standard and percentile curves for the percentage of body fat in children.

6. Conclusion

Obesity triggers several other diseases such as sleep apnea, diabetes, cardiovascular diseases, and others. Worldwide, adult obesity has more than doubled, so it is necessary to act to reduce obesity among the general population. The Quetelet index is a medical standard for determining obesity, but it is impossible to detect normal-weight obesity cases characterized by metabolic dysregulation. With the bioelectrical impedance method, body composition can be accurately determined: the proportion of fat tissue, muscle, and water. It is found that applying easy-to-use technologies such as the TANITA BC 351 body composition analyzer helps reduce obesity and NCDs in the general population. Due to its advantages, the electronic scale should be used to detect the risk of NCDs. In addition to regular monitoring of the BMI, occasional analysis with an electronic precision scale is recommended to obtain a more complete insight into the body composition.

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Designing and Developing an Information System for Subsidizing Student Meal Costs

Suad Kucalović and Hadis Mahmutović

University of Bihać, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina

E-mail: skucalovic1272.tfb@unbi.ba

Abstract. This paper describes the development of an information system for subsidizing student meal costs at universities, with a focus on implementation using the Laravel framework. Laravel, based on the PHP programming language, is one of the leading frameworks today due to its robustness, scalability, and extensive community support. It provides a structured and secure backend development environment, offering built-in authentication, database management, and API integration, making it a powerful choice for web applications. The proposed system is designed to enhance efficiency and transparency in subsidy management through a point-based system, enabling students easier access to subsidized meals. Through a digital platform, students, university administration, and food service providers are integrated, reducing administrative burdens and optimizing the use of public funds. The paper describes the key system functionalities in detail, including point management, through which students receive meal points that they can use for discounted meals at registered food providers and make meal payments, transaction verification and tracking, and report generation, while also offering a simple and intuitive user experience. Additionally, special attention is given to system security, incorporating user authentication and authorization, data protection, and transaction security.

1. Introduction

The lack of an accessible student meal system presents a significant challenge for students in Bosnia and Herzegovina, particularly for those who do not have access to university cafeterias. The absence of such a system often results in increased financial pressure on students and their families, which can directly negatively impact students' academic success [1]. To mitigate these issues, this paper proposes the development and implementation of a digital, centralized system for managing student meals, allowing for easy access to subsidized meals through cooperation between universities and local restaurants.

The core idea of the system is that full-time students would be entitled to a daily subsidy in the form of points, which they can use to partially or fully pay for meals at contracted food service providers. By using a web application, students will be able to choose from available meals and make payments directly through the system, while administrative staff from universities and relevant institutions will have access to analytical reports and consumption statistics without the need for manual tracking or additional workload. This approach allows resources traditionally allocated to administrative tasks to be redirected more efficiently towards increasing the scope of subsidies or other forms of student support.

Currently, there is no universal solution for managing student meals in Bosnia and Herzegovina. Approaches vary from canton to canton, and many procedures are decentralized and administratively demanding. In certain university centers, such as Sarajevo and Tuzla, student cafeterias operate with the help of electronic cards. In these cases, students receive a set number of points each month that can be used for meals in the cafeteria. Although this system provides a degree of digitalization, it has several limitations – students are tied to a single location (the cafeteria), food choices are often limited, and flexibility and interoperability are minimal. Furthermore, universities in smaller communities, such as Bihać, often lack even functional cafeterias, further deepening inequalities among students.

In a regional context, neighboring countries have made significant progress in digitalizing student rights. In Croatia, for example, the X-card and the centralized ISSP (Student Rights Information System) allow students to receive meal subsidies in partner restaurants and student cafeterias. This system enables digital tracking of meals, costs, and subsidy entitlements [2]. In Serbia, an electronic student payment card was introduced in 2023, which, in addition to financial functions, also provides access to various benefits – from transportation discounts to cultural events [3]. However, despite the progress, the focus of these

systems is not solely on flexible and decentralized meal options, but rather often centers around university cafeterias as the primary points of food consumption.

The proposed system differs from existing solutions in several key aspects. First and foremost, it offers a decentralized model that enables students to access a more diverse diet in contracted restaurants, avoiding the limited offerings typically found in traditional cafeterias. Additionally, the system is fully digitalized, with automated report generation for institutions and minimal involvement of administrative staff, ensuring high efficiency and transparency. The web application enables easy user interaction with the system, tracking of daily points and expenses, as well as real-time verification of subsidy eligibility.

Among the limitations is the need for a broad network of partner restaurants to ensure sufficient coverage and dietary diversity. Furthermore, system implementation requires initial investment in infrastructure and coordination between universities, the ministry, and other donors. However, in the long term, the benefits outweigh the costs – through reduced administrative expenses, increased availability of subsidies, and an improved student experience.

2. System Design and Architecture

The most efficient way to implement a subsidized student meal system is through the development of a modern information system based on web technologies. A web-based platform allows easy and universal access for all users, regardless of their location or the device they are using. The core functionality of the system lies in fast, reliable, and secure access to data, which implies the need for an efficiently designed database. The database must be capable of recording all user interactions and transactions in real time while maintaining data consistency and integrity.

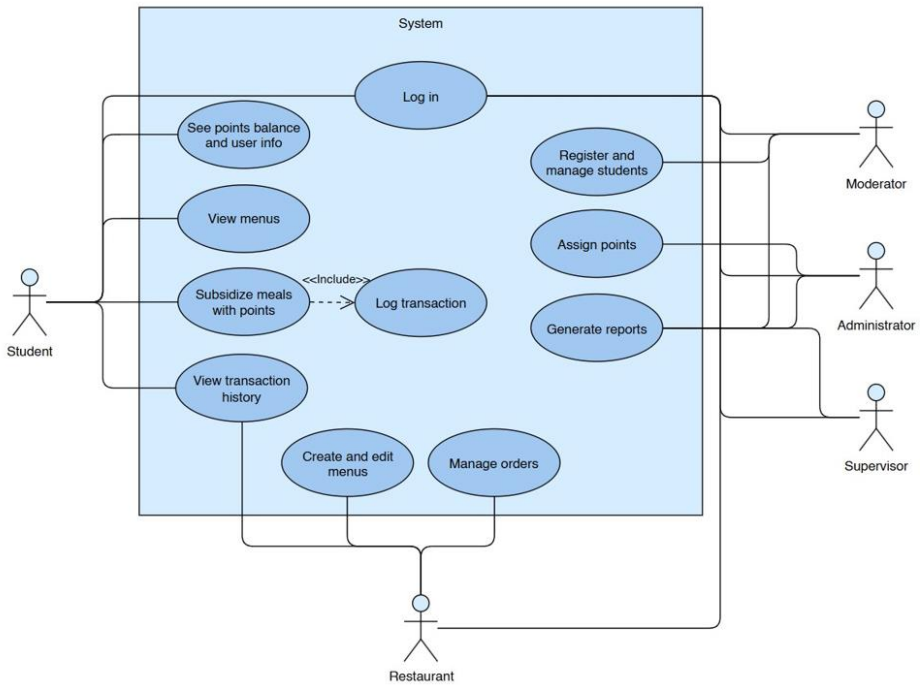

Figure 1. Use-Case Diagram of key interactions between Users and Information System.

The system's user interface should be intuitive, responsive, and visually modern to ensure ease of use and prevent errors caused by misunderstandings. Special emphasis is placed on simplicity of use for technically less experienced users and for everyday use across various devices [4]. The system's technical backbone – that is, server-side logic and process architecture – must be designed to ensure a high level of security, request execution speed, scalability, and fault tolerance.

Given that the system handles sensitive personal and financial student data, it is crucial to implement advanced security measures. The use of multi-factor authentication is recommended both for accessing the system and for confirming meal order requests. These measures significantly reduce the risk of system abuse and unauthorized fund transfers. Every transaction, each subsidy amount transferred by the system to a restaurant, must be recorded and available for user review to ensure transparency and trust.

The system supports three key user types – student, food service provider (restaurant), and administrative staff. Students are the primary users of the system – they can view active restaurants contracted by the university, place meal orders, partially or fully pay for meals using their daily allocated points, and rate restaurant services if needed.

Food service providers (restaurants) have the ability to input meal offers into the system, define prices, manage orders, and view reports on received transactions. The system accurately logs all ordered and fulfilled meals, allowing for simple calculation of subsidies.

Administrative staff have limited access depending on their role. There are three subcategories – administrator, moderator, and system supervisor. The administrator has full access to the system and is responsible for user management, system settings, database integrity, and security policies. The moderator manages student data, including verifying student status and assigning subsidy rights. The system supervisor has read-only privileges. Their role involves monitoring system activity, overseeing executed transactions, and identifying potential irregularities, without the ability to alter any data.

This distribution of responsibilities ensures clear separation of roles and duties within the system, contributing to its security, efficiency, and scalability. Ultimately, the proposed system digitalizes the student meal process, reduces administrative workload, and enables transparent management of public and donor funds allocated for subsidizing student meals.

3. Technologies suitable for the Implementation of the proposed Information System

To implement the information system for subsidized student meals, modern technologies were selected to enable the rapid development of reliable, scalable, and secure web applications. The focus was placed on open-source tools and frameworks that provide a high degree of adaptability and responsiveness. Below are the key technologies used in the development of the system.

The system's backend was developed using the PHP framework Laravel in its latest version, Laravel 12. Laravel is a modern web framework that enables organized and clean code through the MVC (Model–View–Controller) architecture. Laravel offers advanced capabilities for authentication, authorization, routing, database management through Eloquent ORM, and automation of common tasks. Laravel's robust ecosystem further facilitates session management, data processing, and handling of background jobs, all of which are essential for stable real-time system operation [5].

For relational database management, MySQL was chosen due to its speed, reliability, and broad support within the Laravel ecosystem [6]. MySQL allows efficient management of large volumes of data – including information about users, orders, restaurants, transactions, and subsidies – while ensuring data integrity and consistency. By using Eloquent ORM within Laravel, data from the database is easily mapped to application objects, which accelerates development and enhances code readability.

For the frontend part of the application, Tailwind CSS was used – a modern utility-first CSS framework that allows rapid and flexible design of user interfaces. Tailwind CSS enables the creation of fully customizable and responsive UI components with minimal need for custom CSS code. Built on top of Tailwind, the Flowbite framework was also used, offering a set of ready-to-use, accessible UI components (such as tables, forms, modals, navigations, etc.) specifically designed for Tailwind. Flowbite enables fast creation of modern and consistent user interfaces, significantly speeding up development and improving user experience [7][8].

Laravel Livewire is a library used to develop dynamic, interactive components within Laravel applications, without writing JavaScript code. Livewire allows two-way communication between the frontend and backend within the same PHP environment [9]. This technology is especially useful for

functionalities such as real-time meal ordering, displaying restaurant lists and offers, client- and server-side form validation, and more.

The integration of Livewire with Laravel enhances system modularity, provides better control over components, and simplifies application maintenance. This approach avoids the complexity of traditional SPA (Single Page Application) architectures while preserving rich interactivity in the user interface.

Based on a detailed analysis of these technologies, recommendations are made for the optimal technology stack that will enable the successful implementation of the system, considering key factors such as performance, security, scalability, and long-term maintenance.

4. Implementation of the technologies for the proposed Information System

Based on the conducted research in section 3 of this paper, a detailed development plan for the information system is defined, taking into account the selected technologies and best practices for their implementation. The development plan covers the key implementation phases, including requirements analysis, system design, development, testing, and deployment, with clearly defined responsibilities for project participants.

The system implementation plan includes a detailed definition of tasks and resources required for each development phase.

4.1. Database analysis

The database implemented in MySQL consists of 11 main tables, representing entities that interact with each other, as illustrated in the ER diagram (Figure 2). User accounts and their login credentials are stored in a single table, while additional user-specific details are maintained in separate tables, depending on their assigned privileges. Furthermore, the system manages information about the items offered by restaurants and the orders placed by students, which are processed by the restaurants. Based on these interactions, prices are calculated and the transaction process is executed.

This database is designed to minimize data redundancy by optimally utilizing relationships between entities. Additionally, the Soft Delete feature provided by Laravel has been implemented. This involves adding a deleted_at column to key entities, ensuring that records are not permanently deleted from the system. Even if users are removed, their transactions and related data remain intact, preventing accidental loss of important information.

4.2. Integration of Authentication and Security Measures

As part of the security measures, user passwords are hashed, and two-factor authentication is implemented during the login process to ensure the legitimacy of users and prevent unauthorized access or account theft. Route-level protection is also a critical component of the authorization system. Each user can only access routes that are explicitly designed and developed for their role, while shared routes are secured in such a way that only the relevant portion of the page is rendered based on the user's assigned privileges. This ensures that no user can access or interact with functionalities beyond their scope.

Order collection is additionally secured through the generation of a unique code for each order, which the student must physically present at the restaurant to initiate the order confirmation and, ultimately, complete the transaction.

All transactions and order pickups are restricted to working days only, ensuring controlled and secure processing. In addition, every form used in the web application includes a CSRF token to protect against cross-site request forgery attacks [10]. Furthermore, rate limiting is applied to certain forms, such as the login form, to prevent abuse by temporarily blocking users who submit an excessive number of requests within a short time frame. These combined measures contribute to the overall stability, integrity, and security of the system.

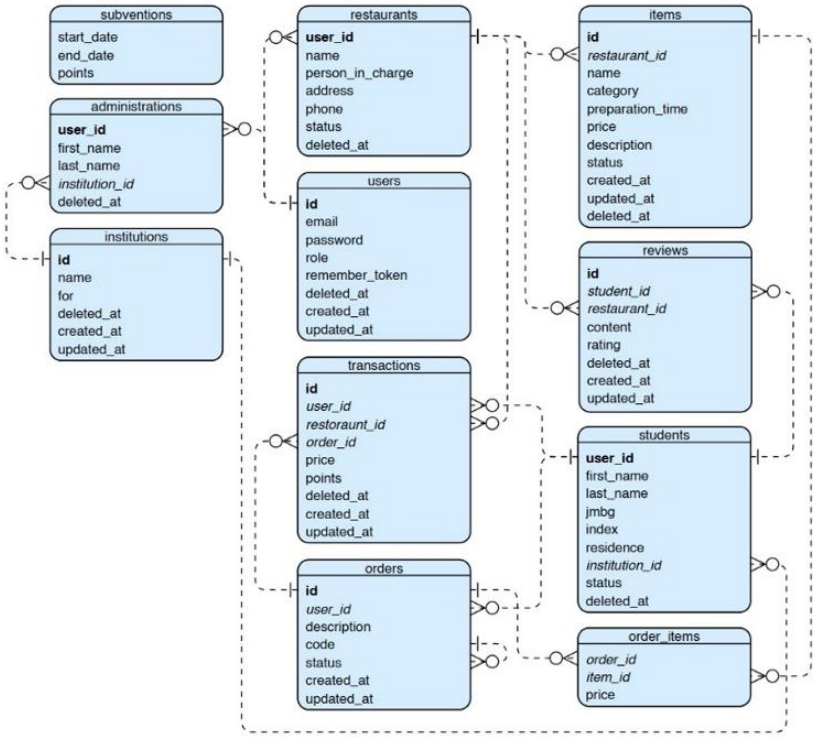

Figure 2. Database Entity Relationship Diagram of the proposed Information System.

Figure 3. Two-Factor verification code sent by Information System to user's email address.

To ensure secure communication between clients and the server, the system operates over HTTPS using SSL/TLS certificates, protecting all transmitted data from interception or tampering. Additionally, the database is regularly backed up, providing a recovery mechanism in case of data loss, corruption, or system failure.

4.3. Development process

The system development was carried out using the waterfall methodology, which enabled a structured, step-by-step approach to each phase of the project, ensuring consistency, predictability, and a clear progression from planning to deployment [11]. The process began with the development of core functionalities essential to system operation, starting with user management, including the creation of user accounts, role definitions, and privilege assignment across different types of users.

Once the user management and administrative interface were established – allowing the definition and oversight of all user roles – the focus shifted to the development of the restaurant interface. This phase included implementing logic for handling orders, menu management, and transaction processing, ensuring that restaurants could efficiently receive and process student orders while maintaining the integrity and security of the transaction process.

Following the successful implementation of the restaurant modules, particular attention was given to the student interface, which was developed as a mobile-first solution, recognizing that the majority of students would access the system via their mobile devices. Due to this, the system was progressively adapted and optimized to support transformation into a Progressive Web Application (PWA), allowing students to install the application on their devices and use it with an experience nearly identical to that of a native mobile application.

Upon completion of all functional modules, the project proceeded to a comprehensive testing phase, covering functional correctness, security compliance, and performance optimization. The system was then refined based on testing feedback and prepared for production deployment, ensuring a stable and user-ready application.

5. Documentation for proper Usage and Maintenance of the proposed Information System

The documentation for the system has been created using Microsoft Word, providing a clear and accessible format suitable for all stakeholders. This user guide offers a comprehensive overview of how to effectively navigate and operate within the system, detailing all available functionalities and guiding users step-by-step through key processes.

The document serves as a general manual, explaining what actions can be performed within the system and how to carry them out. It covers essential topics such as account registration and authentication, point management, transaction handling, and the use of administrative tools for managing subsidies and generating reports. Additionally, it includes important security guidelines and troubleshooting advice to assist users in resolving common issues.

By providing detailed instructions and clear explanations, the documentation ensures that users – from students to university administrators and food service providers – can confidently utilize the system's features with minimal confusion [4]. This structured guide not only supports daily operation but also contributes to the long-term success and sustainability of the system by serving as a reliable reference throughout its lifecycle.

6. Conclusion

The development of the information system for subsidizing student meals represents a significant step towards the modernization and digitalization of student support services in Bosnia and Herzegovina. The proposed system offers a comprehensive and flexible solution that enables full-time students to access subsidized meals in a transparent, efficient, and secure manner. By integrating students, universities, and food service providers into one unified platform, the system significantly reduces administrative burdens and ensures better allocation of public and donor funds.

Through the use of modern web technologies such as Laravel, MySQL, Tailwind CSS, and Livewire, a stable and scalable application was developed, capable of withstanding real-time demands and adapting to different institutional needs. Particular attention was paid to system security, ensuring the protection of

sensitive data and transaction integrity through the implementation of multi-factor authentication, route-level protection, CSRF tokens, and encrypted communication.

The decentralized model of meal provision via contracted restaurants improves dietary diversity and accessibility for students, especially in regions without functioning university cafeterias. The introduction of a mobile-first design and Progressive Web Application functionality ensures that the system is accessible to a wide range of users regardless of device or location.

The proposed system is not only technologically advanced but also socially responsible, providing an opportunity to improve the quality of student life, reduce inequality, and promote transparency in the use of public funds. With the appropriate institutional support and continued development, this system has the potential to become a model for similar initiatives both in the country and in the region.

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Design And Implementation Of Student Performance Monitoring System

Nurfet Mehulić[1], Amel Džanić[1] and Muharem Kozić[2]

[1]University of Bihać, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina
[2]University "Džemal Bijedić" Mostar, Mostar, Bosnia & Herzegovina

E-mail: nmehulic1120.tfb@unbi.ba

Abstract. Student performance monitoring system or „e-Gradebook" is a software application that provides easier access to information and better communication between teachers, parents, and students. This paper describes the system's design using UML diagrams for system structure visualization, including use-case diagrams, class diagrams, and sequence diagrams. The implementation of the system is performed using the Java Spring Boot framework, which is widely used for web applications. Integration with the database and the main components of the system is also described. Software application „e-Gradebook" represents a significant contribution to the digitalization of the educational system in Bosnia & Herzegovina.

1. Introduction

The school gradebook is a book of records used in daily teaching to record student behavior at school, i.e., absences, as well as achieved success in subjects and final success for each school year [1]. In addition to the above, the gradebook also records the schedule of teaching units from the subject and additional student activities such as praise, awards, disciplinary measures, etc. All of the above represents only one part of the data contained in the school gradebook, which can be digitized. Under the influence of the increasingly intensive computerization of all everyday life activities, the idea of digitizing school gradebooks was created [2], respectively developing software applications for monitoring student work called e-Gradebook, which would enable electronic recording of school activities. The main goal of using e-Gradebook is to communicate with parents as quickly, efficiently, and effectively as possible, and to enable them to constantly monitor information about their child's success, such as grades, behavior, etc. The software application "e-Gradebook" is a fast and comprehensive pedagogical tool for registering and monitoring the entire pedagogical process, for increasing interactivity between all stakeholders in that process [2], and for directing them towards building a better and more modern educational system. To design and implement e-Gradebook software, it is necessary to apply various technologies, like UML diagrams, front-end and back-end technologies and quality database. UML is a set of 13 different types of diagrams that can be used to model software systems [3], and is universally accepted as a standard approach for modeling software systems [4]. In addition to UML diagrams, ER diagrams are also used for database modeling. An entity-relationship diagram (ER diagram) helps the database designer identify the data and rules that will be represented and used in the database [5]. After the software is modeled, it needs to be implemented through the application of back-end and front-end technologies. The technologies used to create the e-Gradebook include: Java Spring Boot, MySQL database, and Bootstrap 5. It is important to emphasize that this is just the prototype of software and its use in educational system is yet to be made, also the introduction of the e-Gradebook is not intended to eliminate the use of the classic school gradebook, as there is a legal obligation to keep one, but digitalization would facilitate access to information and data analysis. The research was conducted among parents and teachers of primary schools and high schools, where a voluntary and anonymous survey was completed. The survey collected basic information about the need to use the e-Gradebook, as well as the opinions of parents and teachers about its use.

2. Research on the necessity of e-Gradebook

To better understand the opinions of the teachers and parents about the use of the e-Gradebook, it was necessary to conduct certain research, i.e., the phase of collecting and analyzing requests is being approached. The research was conducted in the area of Cazin and Bihać, and participation in it was voluntary and anonymous. There were a total of 201 respondents, and the research instrument used was an online survey that was created using Google Forms. The respondents' opinions about the e-Gradebook are shown through certain responses to the survey in Figure 1.

Based on the research, it can be concluded that the e-Gradebook would help the work of teachers and also make it easier for parents to see grades and absences. To carry out high-quality software design, it is necessary to collect users' opinions on what they expect from software for monitoring student work, how much such software should be simplified to use, and what functionality it should have in the first version, so that it can be gradually upgraded in later versions. These are just some of the questions that need to be asked of users to deliver quality software that will be quickly accepted for use.

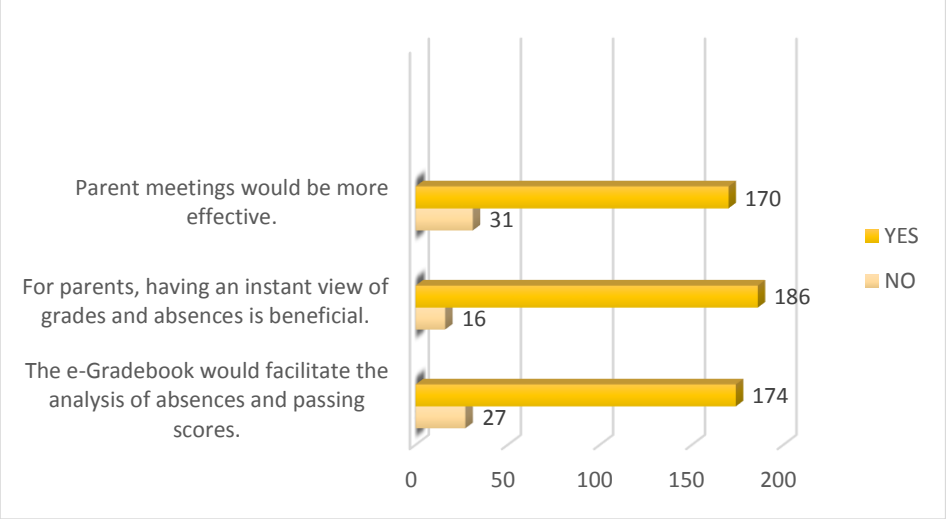

Figure 1. Respondents' opinions on the necessity for e-Gradebook.

In order to collect data on the options that teachers would like in the e-Gradebook, an additional survey was conducted, where 71 respondents from primary schools and high schools in the area of Cazin and Bihać participated. The survey was also voluntary and anonymous. The answers about the desired options are shown in Figure 2.

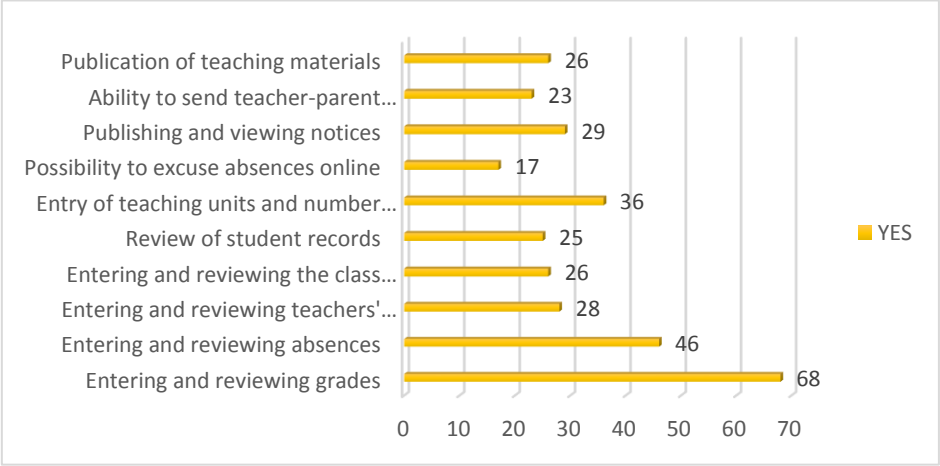

Figure 2. Display of the most selected options for the e-Gradebook by the teachers.

Based on the responses received, it can be determined that the majority of respondents chose the basic options for the first version of the e-Gradebook, which is the ability to enter and review grades and absences, and enter teaching units and the number of hours. Those options were selected where the number of responses was 50% or higher, while the other options can be gradually implemented in the e-Gradebook.

3. Software modeling

After the requirements analysis phase, the design and implementation of the e-Gradebook software is approached, which is why it is necessary to apply different technologies. Sommerville says in Software Engineering that in the software design process UML (Unified Modeling Language) diagrams are used [4], among which the most commonly used are:

- Use Case diagram
- Activity diagram
- Class diagram
- Sequence diagram

In addition to the above, an ER (Entity-Relationship) diagram is also used for database modeling. After the software is designed, it needs to be implemented through the application of back-end and front-end technologies. The technologies used to create e-Gradebook include:

- Java Spring Boot
- MySQL database
- HTML and Bootstrap

3.1. Use Case diagram

This type of diagram represents a simple description of the interactions between users and the system [4]. Each use case represents a discrete task that involves some external interaction with the system.

A use case diagram can be presented for different levels of the system, depending on how many users the system has and what their roles are in its use [6]. Figure 3 shows a first-level use case diagram, which shows a generalization of the system users and their basic interactions with the system itself.

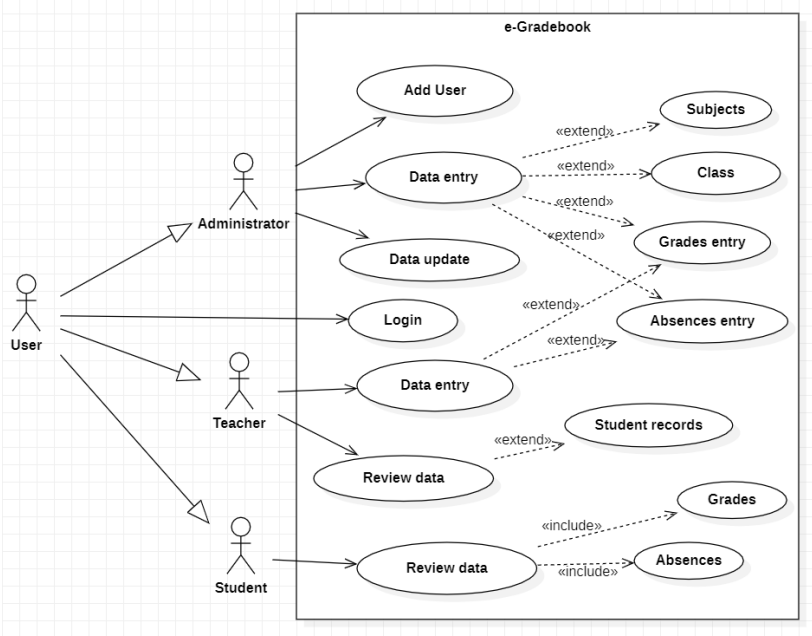

Figure 3. First-level use case diagram for e-Gradebook software.

Based on the diagram shown in Figure 3, specific use cases are created for each user which will represent the second level of use cases, as shown in Figure 4.

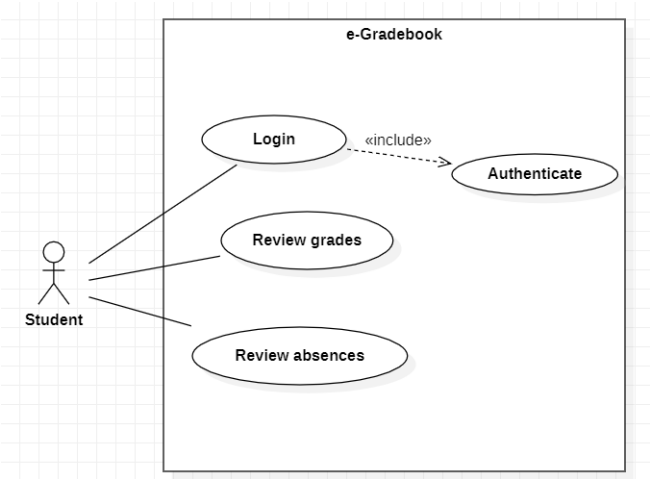

Figure 4. Use case diagram for the user Student.

As shown in Figure 4, for each user of the system, it is necessary to show more detailed use cases, or their interactions with the system. If quality research is done before designing the software and quality use case diagrams are created, it will be much easier to design the entire software based on them.

3.2. Activity diagram

An activity diagram uses use cases to provide a graphical representation of the flow of interactions within a specific scenario [6]. An activity diagram for the user login case is shown in Figure 5.

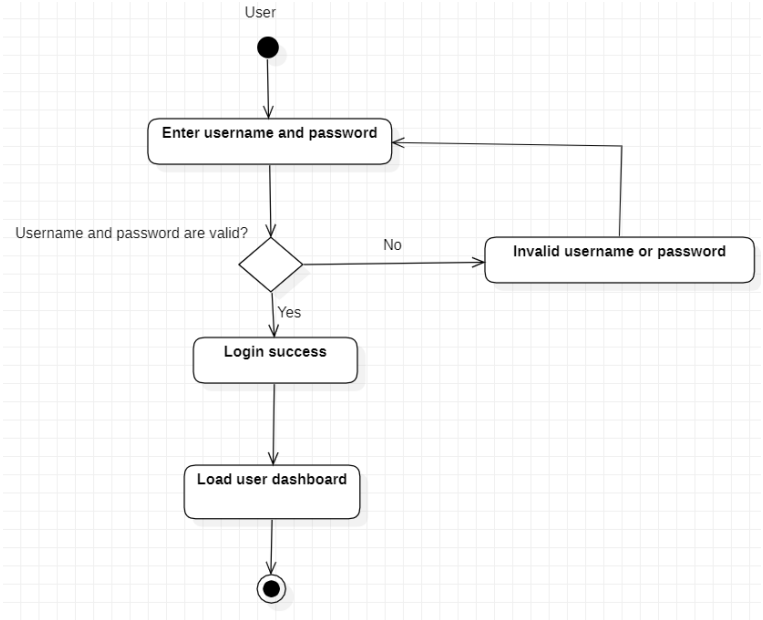

Figure 5. Activity diagram for user login.

An activity diagram can be used to monitor how the program flow will be executed for a specific use case. The diagram in Figure 5 shows the flow of interaction between a system user and their login, and what happens if the login is successful or unsuccessful.

3.3. Sequence diagram

Sequence diagrams are primarily used to model interactions between actors and objects in a system, and interactions between objects among themselves [4]. As the name implies, a sequence diagram shows the

sequence of interactions that occur during a particular instance of a use case. A sequence diagram for user login is shown in Figure 6.

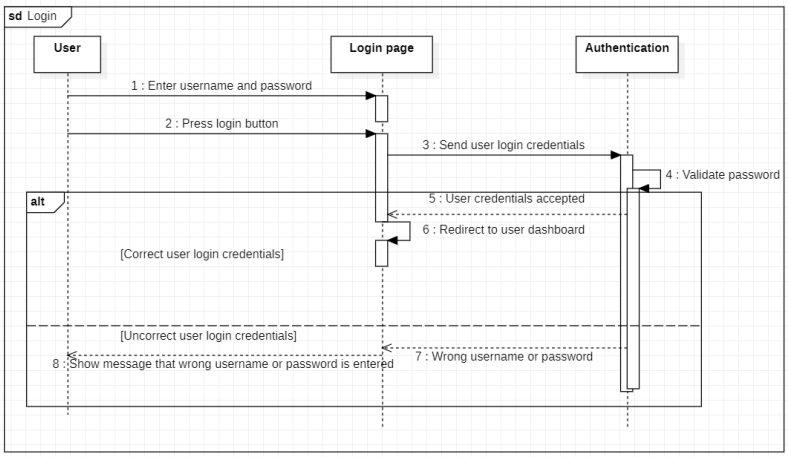

Figure 6. Sequence diagram for user login.

For each type of user shown in Figure 3 of the use cases, the same principle of logging into the system applies. The user needs to enter their login details, and they are checked. If they exist in the database and are correct, the login will be enabled, otherwise, a message will be displayed stating that the login details were entered incorrectly, and the user will have to try again. A sequence diagram is created for each use case, which shows in detail how the system, or software, should function.

3.4. ER Diagram

Song and Froehlich in their Practical guide says entity-relationship diagram is a graphical representation of the conceptual structure of the problem domain being modeled [5]. In other words it shows in which way the database should be created using entities and relationships between them, also it facilitates the database designer in identifying the data and rules that will be represented and used in the database. Figure 7 shows the ER diagram for e-Gradebook.

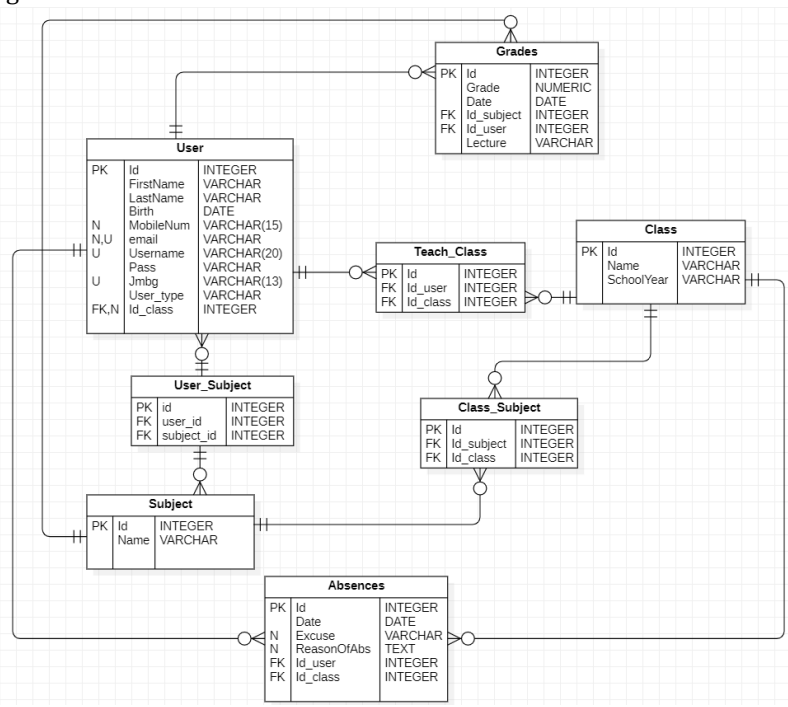

Figure 7. ER diagram for e-Gradebook software.

To create a high-quality and functional database, it is necessary to create an excellent database model using an ER diagram. Based on the created model, it is much easier to implement the database and perform its testing using more complex SQL queries.

3.5. Class diagram

Class diagrams are used in the development of an object-oriented model of a system to show the classes in that system [4] and the associations between those classes. An association between classes is a link that shows that there is some relationship between those classes. Figure 8 shows a class diagram.

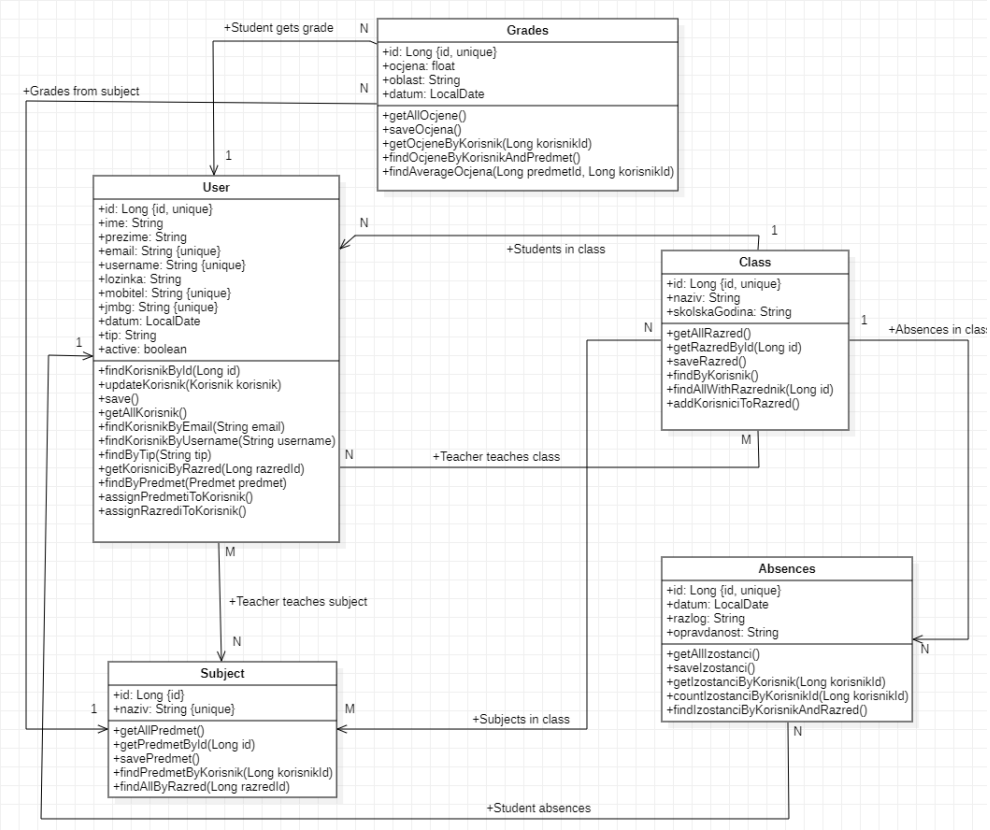

Figure 8. Class diagram for e-Gradebook software.

The given diagram shows the necessary classes that need to be created, their attributes and methods, and the relationships between the classes. After creating the class diagram, you can start implementing the software using an object-oriented approach.

4. Software implementation

Various programming languages and frameworks can be used to implement the software. In this case, the Java Spring Boot framework is used in combination with the Thymeleaf library, which is responsible for displaying dynamic content on the web page.

First, it is necessary to make all the mandatory settings for working with the Spring Boot framework and define the application structure itself, such as setting the application name, database integration, defining the port for HTTP requests, setting the data encryption type, creating all necessary packages, etc. After setting all the necessary settings, you can start creating the e-Gradebook software. It is important to pay attention to the created models using UML diagrams and program the model and REST API controller based on that. The REST API controller is responsible for communication between the client and the server. Database integration was done using Spring Boot and its JPA (Java Persistence API) repository and the Hibernate framework, which are used to map objects to relational tables in the database.

After the back-end part of the web application is implemented, it is important to work on the front-end part, so that the application itself has a well-established user interface that is easy to use. Figures 9 and 10 show the final appearance of the e-Gradebook software.

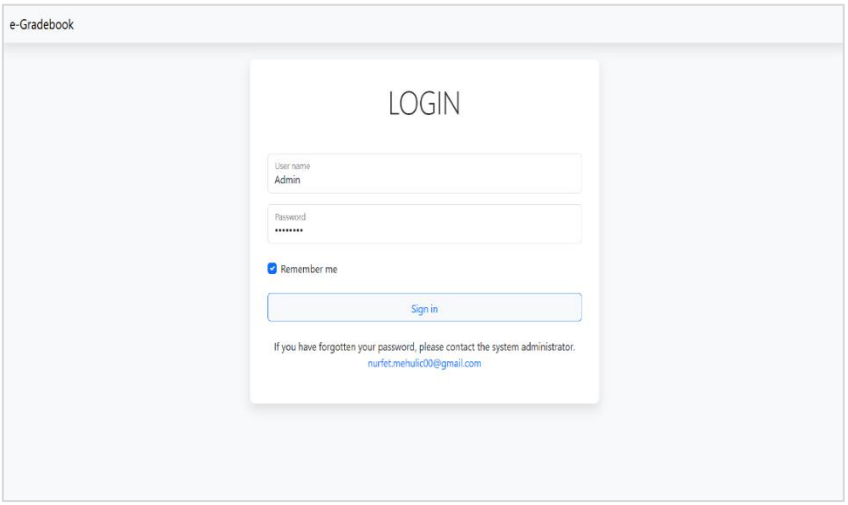

Figure 9. e-Gradebook user login page.

Depending on the type of user, the home pages have different available data and different options.

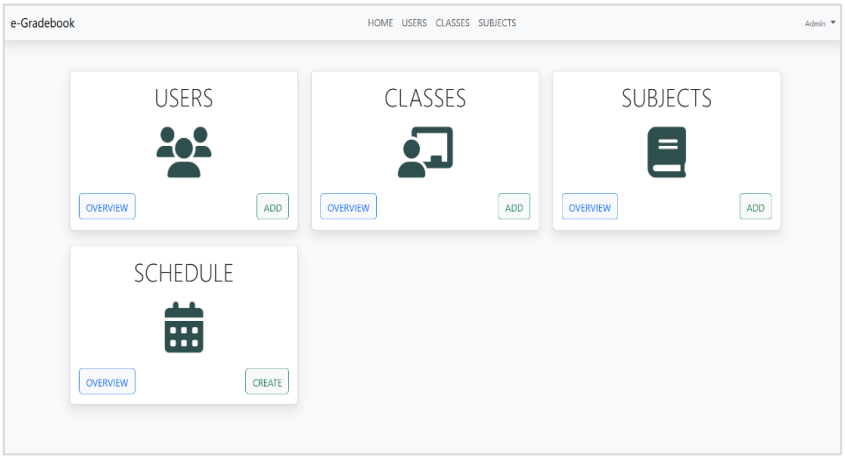

Figure 10. e-Gradebook Administrator dashboard.

The system administrator has activated all the options for easier system management and necessary changes in case of input errors.

5. Conclusion

To create quality software, the first thing that needs to be done is to conduct quality research on the future users of the software, the area of work in which software is used, and the way it will be used. After the requirements analysis has been completed, modeling can start, using some of the software modeling methods. UML diagrams were used to model the e-Gradebook software to obtain a graphical representation of the interaction between the user and the system, and the operation of the system itself. After the system modeling is completed, the database is created, and its testing is performed to avoid errors during implementation. When all the steps for creating the software have been completed, the implementation of the software can begin, and upon completion of the implementation, the necessary testing can be performed to verify that the software is functioning correctly. The process of creating software through all phases is very long and requires expertise and experience in the field, and a team of several people to process the data as efficiently as possible, model the software, and perform implementation and testing so

that it is ready for use. The implementation of this software has satisfied all client requirements, so that parents have constant access to data, i.e., an insight of success in school, while for teachers is made easier to analyse all data during and at the end of the school year, where they can easily and simply keep records and monitor student work. It is important to emphasize that this is only a prototype of the software, and further testing should be preformed before releasing the software to end users.

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The Role of AI in Learning Programming Principles: An Analysis of Benefits, Challenges, and Future Trends

Jasna Hamzabegović[1] and Emina Junuz[2]

[1]University of Bihać, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina
[2]University of Mostar Džemal Bijedić, Faculty of information technologies, Bosnia and Herzegovina

E-mail: jasna.hamzabegovic@unbi.ba

Abstract. The paper evaluates the use of artificial intelligence (AI) for teaching programming fundamentals and their current and prospective implementations. Together with GitHub Copilot, educational benefits such as individualized feedback solutions and more active students as well as faster code implementation debugging processes through Codecademy's Deep seek, can be obtained through machine learning techniques. The worries of student dependence on AI systems are great and are kindle worries related to student´s intellectual superficiality and plagiarism in education due to their high dependence on AI systems. The paper looks at the ethical issues related to using AI in education and discusses how to use it responsibly. Working together with human students, the emotionally adept AI mentors and constructivist training systems help identify and present new learning approaches in the paper. The research shows that the responsibility of teaching, software design, and supervision of artificial intelligence at the same time with proper integration of artificial intelligence to the education process, will bring programming education that is focused and available for students.

Keywords: artificial intelligence, programming education, personalized learning, adaptive learning, AI mentors, integration of artificial intelligence to the education process

1. Introduction

AI is a new approach to studying programming, and programming may help you become an effective educator at your own pace and skill level by providing you with knowledge and experience in a variety of areas. Consider a situation where you are having trouble with a difficult time-taking program late at night. Instead of waiting for your instructor to be available during office hours the following day, you receive immediate assistance from an AI system that not only recognizes the mistake you are making but also explains it to you in simple terms. Additionally, it suggests similar questions you can practice that are tailored to your mistakes. This is demonstrated by Codecademy's AI tutor, Deep seek, and GitHub's Copilot, which all reduce debugging time while providing better concepts [1]. These AI agents are not flawless, though. Students face a serious danger of becoming excessively dependent on the AI and allowing it to correct mistakes without fully comprehending why the solution is effective. When the AI generates entire code blocks for them, some students say they feel like they're merely duplicating responses. Since AI may generate humanized responses in a second focused on the prompt, teachers are also concerned about cheating because it becomes more challenging to determine how work is original. This already occurs with AI systems. Even the degree of plagiarism is not recognized by some AI algorithm [2].

The most interesting developments have taken place in systems that teach rather than give answers. Compared to a human teacher, new "understandable AI" tools [3] are being developed to guide students through their cognitive process step-by-step. AI that understands when an individual is frustrated and modify its teaching strategy correctly is being made by other researchers. Finding the correct balance is important. Students who receive too much AI support may not learn how to tackle problems critically. If there are too few, we lose out on the chance to provide everyone with the personal care that was previously reserved for those who had private tutors. The successful integration of these advances continues to be explored by schools and coding bootcamps, some of which will provide "AI-free" events to help students learn basics before deploying intelligent assistants. One thing is certain: code continues to grow, and there are shrewd ideas coming up one after the other.

2. Background and Evolution of AI in Education

When computers and other similar devices were introduced, teachers, students, and people either used mechanical means of education and learning or simply used human effort. According to Flamm, the 1970s saw the advent of microcomputers and, later, personal computers, which enhanced computational capability and marked an important move to computer technology for the general public [4].

2.1 Historical Development of Computing in Education

With the developments of the electronic computers, more particularly, and the availability of the same for different entities across different sectors of the economy, was precipitated by the developments of personal computers in the 1970s. Personal computers development made it possible for individuals and other non-governmental entities to own and use computers for different reasons. These transitions harbingered the proliferation of computers in different sectors of the economy and society.

The development of personal computers (eg Apple II, Commodore PET) enabled their entry into primary and secondary schools in the 1970s and 1980s. The focus was on programming (LOGO, BASIC) and early computer literacy [5],

2.2 Artificial intelligence in Learning

Artificial intelligence is the result of an ongoing development of computer and information transmission technology. According to Coppin, artificial intelligence is the capacity of machines to deal with unexpected situations, solve issues, respond to inquiries, devise strategies, and carry out a variety of other tasks that call for a degree of intelligence that is normally displayed by humans [6].

In another definition, artificial intelligence as the study of intelligence behavior in human beings, animals, and machines and endeavoring to engineer such behavior into an artifact, such as computers and computer-related technologies. So, it is evident that artificial intelligence is the culmination of computers, computer-related technologies, machines, and information communication technology innovations and developments, giving computers the ability to perform near or human-like functions. In line with the adoption and use of new technologies in education, artificial intelligence has also been extensively leveraged in the higher education sector [7].

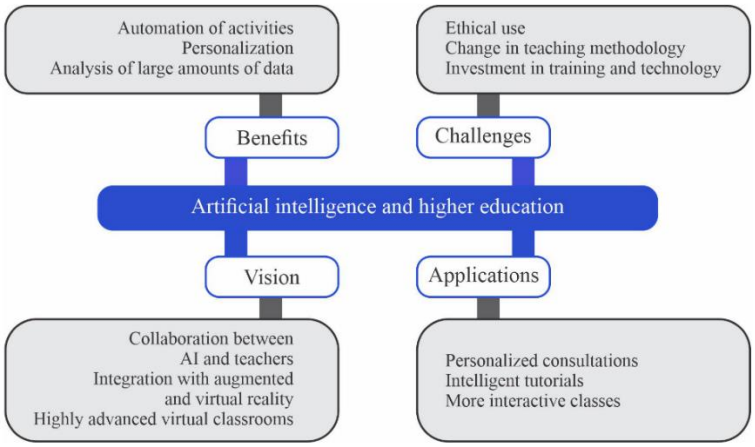

Figure 3. Benefits, vision, challenges, and applications of artificial intelligence in the higher education sector [7].

3. Core Concepts of Artificial Intelligence in Education

AI is defined as a set of technologies that enable computers to perform tasks that require elements of human intelligence, such as recognition, planning, adaptation and decision-making. As Figure 2 shows, three components build artificial intelligence [9]:

1. Machine Learning: Allows computers to learn from data without explicit programming, recognizing patterns and making decisions based on examples.
2. Deep Learning: A subset of machine learning that uses multi-layer neural networks to recognize complex patterns in large data sets, enabling accurate recognition even in complex conditions.
3. Generative AI: The ability of AI systems to create new content, such as text, images or music, based on learned patterns.

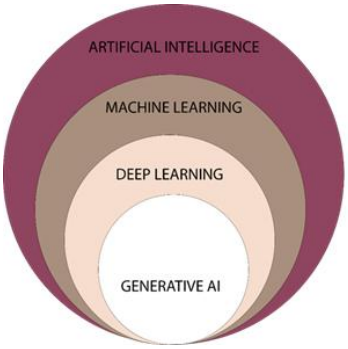

Figure 2. AI vs ML vs DL vs GAI [9].

AI and ML have emerged as transformative technologies in various fields, including education. In the context of adaptive learning, AI and ML play a crucial role in enabling personalized and tailored learning experiences. AI refers to the development of intelligent machines that can simulate human intelligence and perform tasks that typically require human intelligence, such as perception, reasoning, and decision making [10].

3.1 Role of Machine Learning in Personalized Education

The role of AI and ML in gathering and analyzing learner data is crucial for providing personalized learning experiences. Advantages of AI-enabled learning systems include a better learning environment, schedule flexibility, the ability to provide immediate feedback, flexibility in controlling students' learning experiences, and accelerated student development [6]. AI systems can process large amounts of data, learn from patterns and experiences, and make predictions or recommendations. With respect for each student's talents, capabilities, and academic obstacles, AI permits the implementation of a variety of teaching methods.

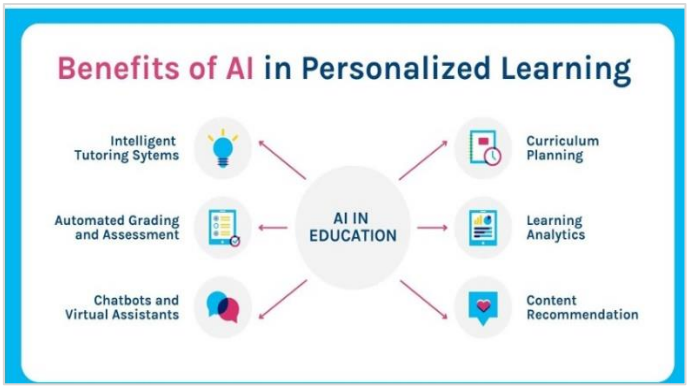

Figure 2. Benefits of AI in Personalized Learning [6].

3.2 Learner Data and Modelling AI Platforms

AI and ML algorithms can collect learner data from various sources, including learning management systems, online platforms, assessments, and digital resources. These algorithms can gather data on learner demographics, performance metrics, interaction patterns, learning preferences, and other relevant

information. Data collection can occur in real time or asynchronously, allowing adaptive learning systems to continuously update and refine learner profiles. AI and ML techniques excel at analyzing large and complex datasets [11]. Once learner data are collected, these algorithms can process the data to uncover patterns, correlations, and trends. Through data analysis, adaptive learning systems can identify individual learner characteristics, such as strengths, weaknesses, learning styles, and knowledge gaps. This analysis forms the foundation for creating personalized learning experiences. AI and ML algorithms can build learner models based on the analyzed data. Learner modeling involves creating representations of individual learners, including their cognitive abilities, knowledge levels, learning styles, and preferences [8]. These models capture the unique characteristics of each learner and serve as a basis for personalizing the learning experience.

3.3 Adaptive learning in artificial intelligence:

Adaptive learning is an educational approach that utilizes technology to provide personalized learning experiences tailored to individual students' needs, preferences, and progress. It leverages data-driven algorithms and artificial intelligence to dynamically adjust the content, the delivery, and the pace of instruction based on learners' performance and engagement. By adapting to the specific requirements of each student, adaptive learning promotes effective and efficient learning, maximizes engagement, and enhances educational outcomes. We explore the significance of adaptive learning in e-learning, highlighting its benefits [10].

In the last few years, e-learning has grown to become a powerful approach to education that offers flexibility, scalability, and personalized learning experiences. Adaptive learning in the context of e-learning refers to the intelligent and dynamic customization of learning content, resources, and activities to meet the unique preferences and needs of individual learners. By analyzing and interpreting learner data, adaptive learning systems can make informed decisions to provide personalized learning experiences, optimize learning outcomes, and enhance student engagement.

4. Benefits of AI-Supported Programming Education

Artificial intelligence in the education of programming has wide ranges of advantage. The methods in which the students engage and absorb programming concepts as personalized learning environment have been transformed by the use of AI based tools that has significantly saved them a lot of time. This section addresses the key benefits such as the offering of learning, e.g. improving engagement, improving performance and the scalability of learning opportunities.

4.1 Enhanced Engagement and Retention

One benefit of the AI in the programming education is the power of AI to increase student engagement, and keep them 'stuck' with knowledge. For instance, debugging tasks generally prove to be a matter of concern for most typical programming courses and therefore it is difficult to keep the consistency of students' motivation efficiently, especially in such courses where there is little immediate class backing. The additional aid this gives is through a type of AI powered platforms like GitHub Copilot and Codecademy's Deep seek [1] that provide instant feedback, personalized guidance and Realtime assistance.

These features can enhance any learning environment in encouraging more interactive and supportive learning environment where a student would be likely to stay engaged when he or she encounters obstacles and may not easily disengage. As a result, it means that consistent engagement can help learning to continue and promote more effective long-term retention of the programming principle.

4.2 Improved Performance and Debugging Speed

AI tools reduce the learning time because students will not need to spend much of their time detecting and correcting errors. Learners receive immediate suggestions, code explanations, even fixes, while learning AIs overlook the syntax or logic errors through manual reviews.

Research shows that AI assistance not only helps with immediate learning, but also improves the ability to solve code errors independently in the long term. Students who used GPT-4 assistance when

solving compiler errors showed a higher level of focus and less frustration and confusion (the so-called confrustion) compared to students who did not use AI assistance, and were more successful in solving errors in tasks where GPT assistance was no longer available, which indicates a more permanent effect of previous AI assistance on error correction skills [12]. Although AI tools can make programming easier, their integration requires carefully designed pedagogical strategies that enable teachers to integrate AI technology in a way that enhances learning, develops critical skills, and maintains high educational standards [13].

Program code generated by AI in languages with a high level of abstraction and automated memory safety, such as Python and Java, proved to be less vulnerable. The reason is that these languages have built-in mechanisms for memory management (eg garbage collection) and safer standard libraries, which reduces the risk of common errors such as buffer overflow, use-after-free, or direct manipulation of pointers. In contrast, languages such as C and C++ proved to be significantly more vulnerable, because they enable direct access to memory, which AI models often abuse or implement incorrectly, especially in the generation of complex functions without adequate security checks [14].

4.3 Scalability and Accessibility

Another important big plus of AI supported instruction is it decimal. AI platforms enable delivering high quality, individualized instruction in time and place desired, no matter location or time zone, to thousands of learners at once. Scalability is beneficial especially when the instructor availability is limited, for example, in the remote and underserved regions. AI takes some of the things that have for a long time kept people away from the exceptional programming education path. In fact, AI tools could take into account all styles of learning and all ways of learning speed; all students should feel trained on a basis of their personal level, something only available with one-on-one tutoring. Also, AI brings more educational equity increasing people's opportunity to learn how to program so that, for example, more people from diverse backgrounds, with different interests, can acquire programming skills [15].

5. Challenges and Ethical Considerations

The undeniable use of AI for programming education brings significant challenges and ethical questions that need proper resolution for responsible deployment. Exclusive attention needs to be directed toward student dependency problems with AI resources and concerns about academic integrity breaches and plagiarism occurrences as well as developing ethical protocols and human-centered control measures. The discussion of these issues should proceed without delay because their delay threatens to harm both future AI education advantages and educational fairness.

5.1 Risk of Overdependence

AI-supported learning environments encounter their most significant challenge through overdependence among students. Students who use AI suggestions will learn to copy answers instead of developing genuine programming skills through basic comprehension [17]. The practice of copying and pasting electronic code leads students to perceive code superficially rather than build essential programming abilities. Machine learning systems have the capability to create dependency in students which inhibits their ability to develop core problem-solving as well as critical thinking competencies both critically important for computer science education. The developers of the platform must create opportunities for students to explore programming material directly while preventing their reliance on the AI features.

5.2 Academic Integrity and Plagiarism

New questions of academic integrity surface with the availability of complete code block generation with AI tools. The way AI generated content differs from regular plagiarism because it contains non-identifiable source material and detecting literal plagiarism becomes extremely hard. Determining student understanding becomes challenging when educators attempt to confirm their submissions through traditional methods. Detection systems used frequently to detect plagiarism fail to recognize content

generated by AI so it becomes more challenging to ensure academic honesty in course compliance. The constant advancement of AI technologies compels industry to create supporting programs which safeguard rather than restrict the educational integrity of programming professionals [16].

5.3 Ethical Use and Human Oversight

AI systems gain independence which produces ethical problems about fairness and transparency and organizational duty. We will operate Metacognition as a Service through AI-based decision processes which produce results that educators together with students cannot easily understand without expert analysis. The absence of transparency produces unintended biases that appear within the delivered instruction. Educational institutions together with technology developers need to invest in technology systems which serve both technical correctness and ethical soundness at their foundation. Educational organizations should develop AI accountability rules to guarantee its responsible application together with human supervision mechanisms which enable periodic checkups to verify fairness and accuracy of the system[18]. Educational institutions must protect teachers in their positions since their human-centered and values-based methodologies need to continue.

6. Future Trends in AI for Programming Education

New developments in AI technology will increase the capability of artificial intelligence systems to interact with humans in an advanced and more human-like manner for programming education. Future versions of AI code generation systems will combine emotional understanding of students with support for constructivist learning frameworks and knowledge construction from learners' current understanding bases and teacher perspectives. Education technology development for the following generation will focus on three key areas: stronger empathy abilities and enhanced agility and better partnership capabilities.

6.1 Emotionally Intelligent AI Tutors

The development of emotion intelligent tutors represents a leading AI innovation in education because such systems achieve student emotional state detection through sensory interaction and respond properly to students feeling frustration or confusion [19]. Their analytic systems study facial expressions and keystroke patterns along with other indicators to identify learners' true feelings in current time. Student overload triggers the AI tutor to modify instruction through simpler tasks while the system also delivers encouragement alongside slower instruction. This adaptive emotional response can create targeted assisting methods which minimize student pressure levels thus leading to continued programming education with enhanced success.

6.2 Constructivist Approaches Enabled by AI

AI systems will provide support based on the knowledge construction paradigm known as constructionism that serves as the standard framework in future technology development. The AI system will function as a learning guide that encourages students through Inquiry and Experiment and Reflection sequences. Students achieve control over their learning and more profound knowledge of programming when this approach is applied because stakeholders gain empowerment. Educational simulations created through AI serve to support students as they work on exercises so the combination of interactive simulations and learner-specific feedback helps minimize challenges with learning time requirements [20]. However, such integration suits very well modern pedagogical theories and increases educational value of AI technologies.

6.3 Human-AI Collaboration in Classrooms

Programming education with AI will lead to enhanced teaching performance by supporting instructors not by replacing them with technology. By taking on black and white grading and error detection tasks and content customization AI frees up time for educators to function as instructional guides and curriculum designers and higher-order learning developers. The emerging relationship provides teachers with

"superpowers" which helps them become more effective at reaching larger groups of students. AI and human educators unite to form an efficient classroom through human empathy and knowledge integration.

7. Conclusion

This modern education is a personalization; it is a scalable and data driven instruction by integrating artificial intelligence in adaptive learning system. A more cohesive and entirely dedicated way of teaching AI has created a revolutionary shift largely and initially because of the very humble origins in computers. Yet they are using the state of the art in machine learning, natural language processing, and predictive analytics to serve self-contained data packaged into eLearning, but also adaptive data about learners and enable the real time provisioning of personalized learning experiences to solve mass problems of education as well as micro problems. In a teaching scenario, applying AI means the system can seamlessly analyses the performance time and again, put the screw on and off instruction levels, timely feedback, fill knowledge gaps to an extent which used to be impossible in traditional classrooms.

Something that needs to also be discussed about implementing AI into an education system is that it does have great potential to completely change education, yet it also has its problems. Ethical issues such as data privacy, algorithmic bias, and reduced human oversight demand careful attention. With the move of taking over the decision making in educational settings, transparency, fairness and accountability are essential. However, there should be strong ethical guidelines in educational institutions to protect the rights of the students and use the advantages of AI in learning the best way. The best part of AI in education lies in its ability to achieve through the responsible use of it, evaluation that must continue, and with the harmonization with human centric teaching practices and values which makes technological enablement but not demonization the ultimate role of educators.

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Serverless Databases: A Comparative Study with Traditional Data Storage Models

Jasna Hamzabegović[1] and Emina Junuz[2]

[1]University of Bihać, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina
[2]University of Mostar Džemal Bijedić, Faculty of information technologies, Bosnia and Herzegovina

E-mail: jasna.hamzabegovic@unbi.ba

Abstract. In this paper we discuss the comparison of serverless databases to the conventional data storage models with focus on the architectural difference, the performance measures, the cost benefit and the use case applicability. In cloud-native applications, more and more are used serverless databases which dynamically allocate resources as needed. However, the infrastructure provisioning and maintenance involve manual operations in traditional databases. This work characterizes the situations in which serverless databases are preferable and when traditional approaches still suit. We provide a guide to how to choose a database system in modern computing environments by evaluating systems like AWS Aurora Serverless, Firebase, PostgreSQL and MongoDB.

Keywords: traditional databases, serverless databases, architectural differences, performance, cost analysis, security and compliance.

1. Introduction

Serverless architectures have gained popularity in recent years due to the need for highly scalable, low, maintenance, highly scalable infrastructures, and cost-efficient computing solutions. One of these is the serverless databases, a model that provides dynamic provisioning of backend infrastructure behind the scenes without administrators directly managing the servers. These are optimized for cloud native applications with ability to scale automatically and with a pay as you go pricing [1].

Relational database management systems (RDBMS) and NoSQL databases [2] have been the traditional data storage models that have been critical in the building of information systems. Unfortunately, they cannot perform well in the modern, agile development environment, which requires them to be dependent on fixed provisioning, complex config, and operational overhead.

In this paper, we examine four fundamental differences between serverless and traditional databases in terms of:

- Architectural design
- Performance under various load scenarios
- Operational and financial costs
- Use-case-based applicability

Our goal is to present a scientific basis for researchers, developers and organizations determining the best data storage strategy.

2. Background

2.1 Traditional Database Models

The traditional database are liked greatly and they include PostgreSQL, MySQL, Oracle DB, MongoDB and SQL Server database systems. On the other hand, these systems are usually implemented under a client server architecture with the impulse being that database server which stays run always active to respond to those incoming client queries. Tuning is usually performed at a number of levels such as query

optimization, indexing strategy and hardware configuration to achieve performance [1]. However, these databases demand users to reserve storage and computation resources in advance, regardless of the time of low usage. In general, scaling the system involves manual scaling (vertical scaling, increasing hardware capacity or horizontal scaling, replication and sharding), which makes the system less easy to maintain. Also, Database administrators are tasked with updating the system on regular basis, maintain system backups and do the system patches. While theseythe operational requirements, operational requirements, traditionally the databases with high configurability are used due to their robust performance and mature ecosystems of handling transactions and large scale of application.

2.2 Serverless Database Models

At the end of the 2010's, serverless database models have appeared as part of broader adoption of cloud native computing. These systems were created to abstract away the management of server provisioning and maintenance in order to ease the management of infrastructure [3]. Some notable examples of the serverless databases include Amazon Aurora Serverless that adjusts the compute capacity dependent on the demand and goes into a paused state, if there is no demand for a certain period; Google Firebase, a real time NoSQL database great for web and mobile apps; Azure Cosmos DB in its serverless tier that provides global distribution and multi model support; and finally, FaunaDB, a fully serverless ACID compliant database with native GraphQL support. These databases are designed to respond to events dynamically and price based on real usage metrics, e.g., reads, writes and compute time. Being developer minimal and especially fitting for burst traffic workload like chat platforms, IoT ecosystems and even for unpredictable workloads applications, they are ideal for agile development environments [4].

3. Architectural Differences

3.1 Traditional Architecture

Meanwhile, traditional database systems are deployed on virtual machines, containers or dedicated physical server, and users are responsible for fully provisioning and managing the underlying infrastructure of the server [5].

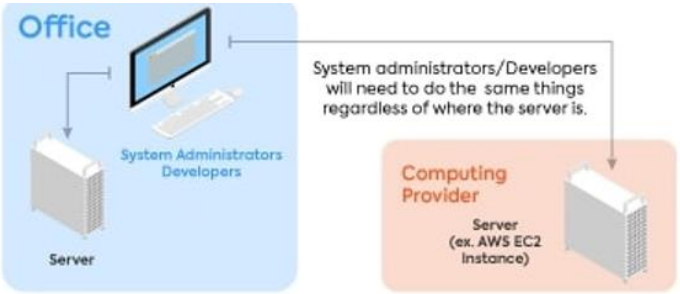

Figure 1. Traditional Approach[5].

The Figure 1 illustrates traditional approach to server management. That is to say about allocating CPU and memory resources, configuring storage volumes, setting up as networking and firewall rules, and for policy in system monitoring and scaling. High availability (HA) is the first requirement of a traditional databases, but it relies on those mechanisms of replication, clustering, and failover, and usually it requires manual setup and maintenance. For this reason, these systems deliver consistent performance when it comes to transactional performance and can handle complex joins, stored procedures, and sophisticated query operations. Additionally, traditional databases have a strong compatibility with the existing legacy systems, and this makes them a great choice for the enterprise who has already established the software environments and processes in place.

3.2 Serverless Architecture

Serverless architecture allows developers to focus on code, while full infrastructure management is left to the cloud provider e.g. AWS Lambda, Google Cloud Functions, Azure Functions (Figure 2).

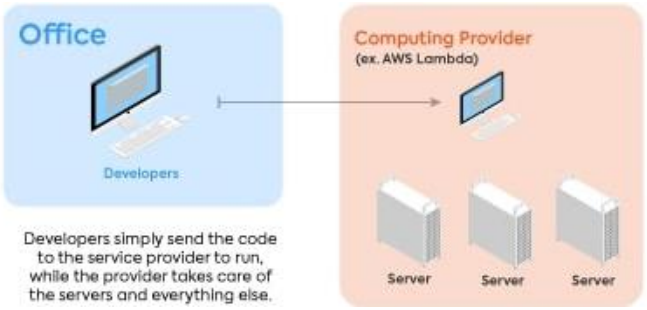

Figure 2. Serverless Architecture [5].

Serverless databases are architected without the need for manual infrastructure management. In serverless models, cloud provider handles provisioning and maintenance of underlying infrastructure, such as compute resources, memory allocation and storage, and the logic layer(s) is written up to slim that also runs within the cloud provider VM[5]. System automatically expands or shrinks its size according to How many active connections, how much workload, will cost reduce or not. With this abstraction removed, developers are no longer required to interact with the operating system or its configurations. Serverless databases have been built to play well with the modern software development paradigms like microservices, event driven software, as well as continuous integration continuous deployment (CI/CD) pipelines. So they have a significant impact on speeding up development cycles and reducing the cost of operations traditionally involved in database management.

4. Performance Comparison

4.1 Latency and Cold Starts

It is known that traditional databases provides its continuous availability and predictable capacity allocation, which is known to be consistent low latency [6]. If configured correctly, there is little or no delay between the receipt and processing of a request, and they will be almost perfect for any application where real time response is required. However, as far as performance is concerned, application that is less than ideal in terms of condition, but smart enough to use care indexing, should not deteriorate when users hit hard or query cases other than optimal.

While serverless databases are flexible but suffer from cold start problem, but they also have great cost savings made available. A cold start will have an initial delay as it is going to spin up an inactive database for a request to handle. This is actually true in many systems where, for example in Amazon Aurora Serverless, resources are deallocating when the system is idle to reduce cost. Cold start is addressed by providing the optimisations like Connection pooling and Instance warming provided by the providers to minimize latency, but this latency that may arise due to reactivation, can really compromise the performance bound applications, for the first request that comes after an period of inactivity of a certain span [7].

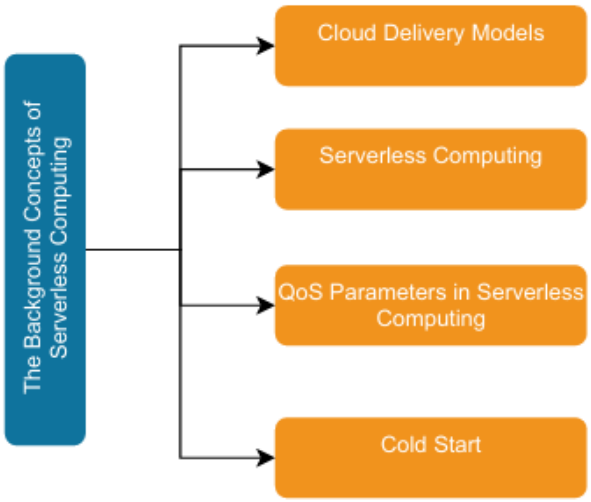

Figure 3. The Background of Serverless Computing and Cold Start [7]

This cold start challenge is placed in the context of the broader serverless computing architecture, as shown in Figure 3, which illustrates the basic concepts of a serverless approach. The diagram includes four key components: cloud delivery models, serverless computing, serverless QoS parameters, and cold start. The diagram shows how "Cold Start" emerges as a distinct and significant challenge within the serverless architecture ecosystem, along with quality of service parameters and cloud delivery models. This further emphasizes the importance of understanding cold start in the context of performance and reliability of modern cloud-based applications.

4.2 Scalability

One of the main difference comes from the approach towards scalability between the two models. For additional capacity of traditional databases, vertical scaling is used new instance is created and the current instance is replaced by the new more powerful instance with a larger CPU, increased memory or increased disk. However, this approach results in larger risk in downtime risk, but it is also easier to bear the cost of this approach with respect to accommodating larger workloads. To scale out the horizontal dimension, such as when one needs to scale out the horizontal dimension, sharding or replication are often implicated, leading to an application design which tends to be complex and operationally complex process in the distributed system [8].

And one of the great things about serverless databases is that this automatic scaling usually comes along with it naturally as the serverless environment launches (or expands or shrinks) the amount of compute and memory required on its own without any help from the developer. In the case of Amazon Aurora Serverless, the database compute capacity runs automatically in seconds when the load of the database changes [8]. So in other words, serverless models can be more spry to traffic spikes and/or fluctuating loads, without getting resource bottlenecks and requiring less hands on scaling policies.

4.3 Throughput and Workload Suitability

However, serverless databases have quite low throughput compared to traditional ones when job loads are for extended periods of time. Both minimalist resource commitment and flexible builds are at once quaint and perfectly retrofit together through all (and some very 21st century ways) [9] which computing has found to use a box setup to saturate the connections within it, the bulk data processing, settling the complex transactions and cradling the unbounded queries. A traditional database is most commonly used by the enterprises that depend on the stability of the enterprise and predictability of performance when these enterprises use data warehousing, analytics or e-commerce.

Nevertheless, serverless databases are suitable for the use cases where the workload is random or inconsistent. If used with serverless, serverless models are great for usage bursts that appear in

applications such as chat apps, event loggers or api backends; where they can scale very fast when needed and very fast when not. This however does not mean that serverless databases can't be throttled and usually is not as granular as traditional systems especially when there are a large number of concurrent requests and/or requests. These constraints only allow the applications to have lower throughput for performance critical applications [10].

5. Cost Analysis

5.1 Pricing Models

All modern cloud-based databases are based on a consumption model, where users pay only for the amount of resources they utilize. In development environments or applications with occasional traffic, this model increases idle costs. In addition, operational costs contain expenses for maintaining the system, backups, patching, personnel time, etc. Over time, the total cost of ownership can be significally increased by these factors [11].

Instead, serverless databases are priced on an 'as you go' basis meaning users only get billed for what they actually consume. Then, pricing is normally based on counts of read/write units, the amount of active compute time (in seconds), maximum concurrent connections and total storage used [11]. The granular billing model of serverless databases is what particularly appeals to startups and small businesses or pilot projects on a limited budget where control of costs is essential and workloads change. Serverless models operate as users don't pay for idle time or unused capacity, which make serverless efficient resource allocation and lead to possible big cost savings in situations where traffic is inconstant or unpredictable.

5.2 Comparative Example

Comparison of the cost structure is clearly made between the economic tradeoffs that come with the traditional and serverless database models. PostgreSQL and other traditional datasets leave it up to you, the user, to pay the full amount, regardless of whether it has been provisioned or is active [11]. For this, the idle costs are high and there is an issue of manual scaling or failover. In addition, there are also operational costs for maintaining and updating, which are not in full automation. Using serverless databases (e.g. Amazon Aurora Serverless) enables automatic scaling of database capacity based on application needs, charging only for the resources actually used. This model eliminates downtime costs and reduces the need for manual scaling or maintenance.

While the traditional model may be more cost-effective for applications with a constant load, the serverless model offers greater flexibility and potential savings for applications with variable or unpredictable loads.

6. Use Case Evaluation

6.1 Web and Mobile Applications

Serverless databases are fed in web & mobile applications with high time dependent usage or regional traffic spikes due to their scalability and cost efficiency. However, there are platforms for mobile app developers to choose from such as the platforms offered by Google Firebase like real-time synchronization, simple integration, cross platform, and so on. Second, serverless databases are particularly useful where applications, such as social media platforms, messaging apps or casual games, need to be scaled with real time data exchange, but the user activity flexes and hits the highest or lowest when they work [10].

Table 1 shows a comparison of AWS Aurora Serverless, Azure Cosmos DB and Firebase Firestore, including reliable sources from the official documentation [12][13][14].

6.2 IoT and Event-Driven Systems

Table 1. Comparing AWS Aurora Serverless vs. Azure Cosmos DB vs. Firebase Firestore.

Feature	AWS Aurora Serverless	Azure Cosmos DB	Firebase Firestore
Database Type	Relational (SQL)	NoSQL	NoSQL
Best for	Web apps, microservices, analytics	Global apps, real-time AI, NoSQL storage	Mobile/web apps, chat, real-time sync
Scaling Model	Auto-scaling compute & storage	Horizontal scaling across regions	Auto-scaling, real-time sync
Global Distribution	Multi-AZ support	Multi-region replication	Limited to Firebase regions
Cost Model	Pay-per-use	Per-request billing	Pay-per-operation
Ideal Use Cases	Traditional RDBMS workloads, event-driven apps	AI, multi-region apps, IoT data	Real-time apps, notifications, games

In IoT ecosystem, the devices are continually flowing streams of events or sensor readings. We were looking to ingest and process these workloads in a non pre provisioned capacity database, which are bursty and asynchronous workloads. This has also made serverless databases a great fit for an event driven architectures and serverless compute platform like AWS Lambda or Azure Functions. Such applications, including telemetry data real time processing, dynamic storage and analysis, have serverless models as the right choice for their integration, because it provides support for the real time processing of telemetry data, storage and analysis without manual scaling of resources [15].

6.3 Enterprise Systems and ERP

Consistency, durability and integration with the business Intelligence tools are required, which are characteristic of large-scale enterprise systems like Enterprise Resource Planning (ERP), Customer relationship management (CRM) and other transactional systems.

Traditional relational databases, such as Oracle and Microsoft SQL Server, offer the predictability and control that are critical for applications that rely on large data sets and require regulatory compliance. Also, these databases are suitable for applications that require high availability, compliance with regulations and communication with legacy infrastructures [1].

6.4 Analytics and Data Warehousing

Data analytics and warehousing deal with very large historical data and queries on it are complex. Traditional data warehousing systems, such as Amazon Redshift and Snowflake, use colonial storage, parallel query execution, and indexing to enable efficient processing of large amounts of historical data and complex queries. These characteristics make them suitable for applications that require high consistency and performance, such as business intelligence and analytics systems[16].

Serverless databases are efficient for the operational workloads, but they do not have advanced indexing, batch querying support, or OLAP support that is needed in analytics use cases. Consequently, traditional systems are still used as the preferred choice for Data Warehousing and Business Intelligence applications.

7. Security and Management

7.1 Access Control and Auditing

Top of the list of factors that we consider in database architecture is security[17]. On the other hand, traditional databases provide fine grained access control mechanisms such as role based access, custom user privileges as well as logging and compliance at fine grained level. In multi user environments, these databases can work with enterprise grade identity and access management systems such as those on the market today, LDAP, Active Directory, Kerberos, and provide a high level of control and accountability.

Serverless databases, in contrast, abstract much of the access control management behind cloud provider IAM (Identity and Access Management) systems. Though they provide simplified user provisioning, the models need not be granular or customizable enough for systems where high levels of regulation are present. As one example, Firebase employs Google IAM roles for access control, but enforcing more sophisticated permission models within an organization can be challenging, and meets auditing standards in finance, healthcare, and government sectors[17].

7.2 Vendor Lock-in

In choosing the serverless database, vendor lock in is a big factor. Portfolio of services often uses the proprietary APIs, configuration and data model hence hindering the portability across cloud platforms. Moving from a serverless platform could mean relocating from cloud to cloud, i.e. data export, source code refactoring, changes in infrastructure as code pipelines and additional costs[18].

More portable and more deployable as well, traditional databases. All of these can be hosted on premises, or in a virtual machine or some combination of cloud providers, allowing organizations to maintain control of their data infrastructure. However, this flexibility is important to businesses looking to minimize dependency on only one vendor and want them to continue to maintain multi cloud or hybrid cloud strategies [19].

8. Discussion

Choosing a tradition or serverless has many factors to determine and depends on various factors. Further, the experience level of the team is very important: smaller teams and startups lacking DevOps resources may choose serverless models for its more operational simple nature and automation. However, organizations with established IT teams might find more comfort in utilizing traditional databases' flexibility and control rather than a traditional database [19].

From a cost perspective, serverless databases make more economical sense for using applications where the usage can be low or very variable. Nevertheless, for long term, high loading operational film thickness, the cost performance ratios that traditional models provide may be superior. The performance requirements are also major the traditional systems still enjoy a higher throughput and customization compared to more recent ones, with real time analytics, batch processing and complex transactions [11].

Traditional databases win the competition even more for security and compliance in the regulated industries, where there are strict granular auditing, access control and data residency requirements. Serverless models are yet to match the enterprise grade traditional system in these areas, although they are getting better [17].

Table 2. Traditional vs Serverless Databases – Key Comparison Factors

Decision Factor	Traditional Database	Serverless Database
Team Profile	Preferred by mature IT teams	Preferred by startups with fewer DevOps resources

Cost Efficiency	Better for long-term, high-load scenarios	Better for variable or low usage
Performance	High throughput, customization, complex transactions	Sufficient for moderate, event-driven loads
Security & Compliance	Strong granular control and auditing	Improving, but less granular
Flexibility & Control	Highly customizable, deployable anywhere	Less flexible, dependent on provider

Finally, both these models find their place in the modern software architecture. You can have the best of both worlds by using a hybrid approach where serverless databases are used for workloads that expose to the end user, but traditional databases at core transaction level. Table 2 summarizes the key decision-making factors when choosing between traditional and serverless database architectures.

9. Conclusion

In this paper, we compared serverless databases to typical data storage models based on their architecture, performance and how much it costs you, as well as the use cases where they are suitable. Serverless databases eliminates infrastructure and automation provisioning of data, delivering it in a modern, elastic and cheap way. These systems serve perfectly for workloads with change, few operators, or fast development cycles. But on the other hand, however, enterprise large scale systems, super premium, and comprehensive traditionally still prefer to go with traditional databases because of low latency predictions, allow fine tunning optimization, and established developed security frameworks.

Although serverless databases have changed the backend development, but are not panacea. There's a lot to be careful with when it comes to weighing in about a load that performance will respond to, how quickly it would start up in cold conditions, vendor lock in and the limited advanced querying features. Traditional model still plays critical role in business critical system, analytics, and regulation. So they boil down to the policies, priorities of your organisation: how much resources do you have and what do you need from an application. Many research and development gaps remain. These include areas where further innovation, standardization, or optimization can significantly improve the effectiveness and adoption of serverless database architectures: cold start pptimization, advanced query support, interoperability and vendor lock-in, security and compliance, performance benchmarking and optimize hybrid orchestration and cost-performance balance.

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Implementation of a Software Solution for Detecting and Preventing Memory Manipulation Cheating in MMOGs

Jasna Hamzabegović, Elmin Midžić and Amel Džanić

University of Bihać, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina

E-mail: jasna.hamzabegovic@unbi.ba

Abstract The competitive nature of gaming makes it a good place for attacks aimed at disrupting a rival or granting unfair advantages to players. One increasingly common method involves players manipulating the local memory of their computers to gain an unfair edge. This paper explores the issue of cheating in massively multiplayer online games (MMOGs) through a combination of theoretical analysis and the development and implementation of a software solution for detecting and preventing memory manipulation. The developed software solution operates by having the server verify the integrity of the game by comparing all key client files with previously generated checksum files of the original game client. This approach ensures that players cannot locally alter their instance of the game. As a result, the system provides effective protection against cheating, promoting fair and balanced gameplay for all participants.

Keywords: massively multiplayer online game (MMOG), cheating, memory manipulation, anti-cheating measures

1. Introduction

A massively multiplayer online game (also known as MMOG or simply MMO) is a type of computer game that allows hundreds or thousands of players to interact simultaneously within a game world they access via the Internet [1]. An MMOG differs from a traditional multiplayer game in that its environment is persistent. The game world continues to exist and evolve even when individual players are offline.

MMOGs are extremely popular today, with both the number of players and revenue from online games steadily increasing. It is expected that the video game market will double from 2023 to 2033. According to the company Brainy Insights, revenue could reach 490 billion dollars by 2033. This is a significant increase compared to the 2023 revenue, which was below 250 billion dollars. The main driver of this growth is mobile gaming, which is booming thanks to advances in smartphone technology. Therefore, the video game market remains one of the fastest-growing sectors in technology [2].

This is good news for all game providers and developers, but this market also attracts cheaters. There are numerous security issues that negatively impact both game providers and players. As early as the 2000s, cheating became a major security issue for online computer games [3]. In this context, cheating refers to any behavior by which a player gains an unfair advantage that they should not have achieved under the rules of the game [4]. Collaboration between developers, publishers (providers), and players is crucial in the fight against cheating. To protect the gaming experience and ensure the economic success of video games, developers must create games that are protected against cheating and that offer a fair and enjoyable environment for all players.

Players often express concern about the intrusiveness of anti-cheat software, especially those that operate at the kernel level, as they can affect privacy and system performance. For publishers, video game security is important for preserving brand reputation and financial stability. While effective anti-cheat measures can help retain loyal players and prevent revenue loss due to cheating, publishers often struggle with the dilemma of implementing stricter security systems while maintaining a positive user experience, since overly restrictive methods can lead to bad publicity or the loss of some players. Therefore, all three

groups recognize the need for good anti-cheat measures, but it is important to find a balance that preserves fair play without disrupting the privacy and experience of legitimate users [5].

2. Background

Traditional game security once focused primarily on protecting software code and preventing piracy. However, the growing popularity and economic value of MMO games have made them prime targets for malware and online cheating. With the emergence of MMOGs, security has become a broader concept that includes player authentication, protection of virtual assets, fraud and cheat prevention, and resistance to server attacks [6].

Today, most revenue in MMOGs comes from the pay-to-play model rather than direct game sales. The last few years have seen a shift from buying the actual games (and sometimes their monthly subscriptions) to free games (Free-to-Play, F2P) in which the player can eventually spend real-world money. Known as a 'microtransaction', the gamers can purchase additional items, bonuses, or services inside the game [7]. This shift has introduced new security challenges, as it motivates attackers to target player accounts and virtual property for the theft of real-world value.

2.1 Perception and Context of Cheating in Video Games

Cheating in video games is a phenomenon that evolves and grows along with the video game industry and its technologies. It is not a fixed category, but depends on the context of the game, the rules set by developers, and community norms. What may be considered cheating in one game could be entirely acceptable in another, as the boundaries between fair play and cheating are often unclear.

Each game has its own specific design and mechanics that influence what is considered cheating. For example, in single-player games, the use of cheat codes in titles like GTA or The Sims is often not regarded as cheating, since it does not affect other players. In those games, players often cheat to experiment with the game world or to ease their own progress. In multiplayer games such as Counter-Strike: Global Offensive or World of Warcraft, the use of aimbots or modifications that provide unfair advantages is considered serious cheating because it directly disrupts competitive balance and harms other players [8].

Cheating can have a contagious effect within online communities. Some researchers emphasize that the likelihood of a player starting to use bots increases if they have friends who already cheat. This phenomenon is attributed to social influence, where the success of cheaters motivates their friends to engage in similar activities [9].

2.2 Perspectives on Cheating in Video Games

Cheating evolves rapidly alongside technological advancements, forcing game developers to continually upgrade their protection systems to combat increasingly sophisticated cheating methods.

To reduce the chance of client-side data manipulation and ensure that players cannot alter key parts of the game, developers must implement server-side verification. They also employ anomaly detection by analyzing player behavior and identifying patterns that suggest bot use or illegal modifications. Additionally, developers create security protocols to prevent network attacks, such as packet manipulation or exploitation of vulnerabilities in the game's code. Since cheating is constantly evolving, developers must respond quickly with updates and new protection methods to maintain a fair competitive environment [10].

3. Material & methods

This research employs a methodological approach that includes a review of existing literature and an analysis of cheating methods in MMO games. Various academic sources, industry reports, and technical specifications were analyzed to gain a clear understanding of the current challenges and security mechanisms in online gaming. Special focus was placed on memory manipulation, cheat detection, and prevention strategies.

The research methodology consists of four main parts: a literature review on cheating in MMOGs, a theoretical analysis of the problem, the development of a software solution for cheat prevention, and experimental testing.

3.1 Literature Review

Cheating in video games has attracted the attention of both academic researchers and industry experts due to its negative impact on fair play and the player experience. Yan and Randell [11] classified cheating based on technical approaches, while Jeng and Lee [12] examined protection methods, emphasizing the importance of server-side verification. Blackburn et al. [13] explored how cheating can influence online groups and found that when a cheater is present in a game, other players are more likely to start cheating as well. Hu and Zambetta [14] studied the moral aspects of cheating in both single-player and multiplayer environments.

Han et al. [15] provided a detailed description of memory manipulation as one of the most common cheating techniques in MMOGs, emphasizing that standard protection methods are often insufficient to detect these attacks. Their research shows that combined approaches - merging anomaly detection and memory analysis - are the most effective in preventing cheats.

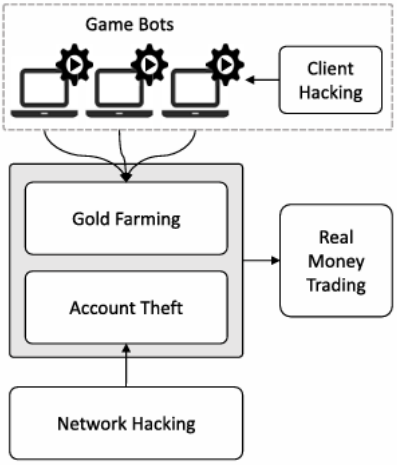


Figure 1. Mechanisms of each cheating in MMORPGs [15].

This research builds on prior work but contributes to the field by developing a unique security system that integrates server-side verification, anomaly analysis, and the use of advanced security protocols. The goal is to ensure a high level of detection while minimizing false positives through systematic real-time evaluation of cheating behavior.

Academic sources were analyzed that classify cheating methods, including game memory modification using tools like Cheat Engine [15], code injection into game processes to alter their functions, and packet manipulation, where data transmitted between the client and server is tampered with.

3.2 Theoretical analysis

MMO games provide all players with equal amounts of temporal and spatial resources [16]. However, the expansion of these games across multiple platforms (PC and mobile) has led to an increase in cheating incidents. Cheating undermines the principle of fair play, negatively affects users, reduces their engagement, and may cause them to abandon the game altogether [17]. Additionally, cheating shortens the lifecycle of games and results in economic losses for game publishers and developers.

To offer a better understanding of how to effectively manage strategies for detecting and combating cheating in online games, several cheating methods, their consequences, and detection techniques have been explored [15].

MMORPG (Massively Multiplayer Online Role-Playing Game) is a specific subcategory of MMOGs that focuses on role-playing (RPG).

Figure 1 illustrates how cheating, which frequently occurs in this specific type of MMOG—namely, Massively Multiplayer Online Role-Playing Games—is organically structured. It includes the use of game bots, illegal private servers (unauthorized replication or production of source code for specific games), account theft, gold farming groups, and real-money trading [15].

Stateful game server

The so-called stateful game server plays a significant role in MMORPGs and real-time multiplayer environments. This type of server retains user session information during interactions, allowing for continuous tracking of game state in MMORPGs. It stores data about players, their locations, inventories, NPCs, and progress in real time, enabling complex game mechanics such as combat, trading, and group activities. The main advantage is consistency and synchronization of data among all players; however, its downside is higher resource consumption, as it requires constant memory processing and data retention. If a failure occurs before data is permanently saved to the database, there is a risk of losing player progress.

Although stateful servers are essential to the operation of MMORPGs, they pose a security challenge because they continuously store and process player data in real time, making them a target for attacks and manipulation. Attackers can exploit vulnerabilities to alter the game state, duplicate resources, or perform character "teleportation." Moreover, client-side data manipulation enables cheating through memory hacking, potentially resulting in unauthorized level-ups or unlimited resources. SQL injections and database attacks can allow cheaters to directly modify server data and gain unfair advantages. Due to these risks, advanced anomaly detection, data encryption, and server-side validation are necessary to prevent manipulation and maintain fair gameplay [15].

Figure 2 illustrates the structure and logic of a stateful server in MMORPGs, where a central server manages all game aspects in real time. Key elements are shown, including client programs that are continuously connected to the server, enabling synchronization of character data, locations, NPCs, and in-game events. The server processes all player actions, such as combat, trading, and movement, stores them in memory, and then updates them in the database to maintain game consistency. If the server crashes before data is saved, there is a risk of losing player progress, highlighting the importance of robust security and backup mechanisms [18].

Cheating on Stateful Servers

Cheating in MMORPGs that use stateful servers most commonly relies on manipulation of data exchanged between the client and the server. Attackers may intercept network packets, modify data in the client's memory, or exploit server vulnerabilities to gain unfair advantages. Common forms of cheating include item duplication, character teleportation, exploitation of data synchronization bugs, and the use of bots that automate gameplay. Additionally, SQL injections can allow attackers to directly modify server database data, potentially increasing resources or unlocking premium features without payment.

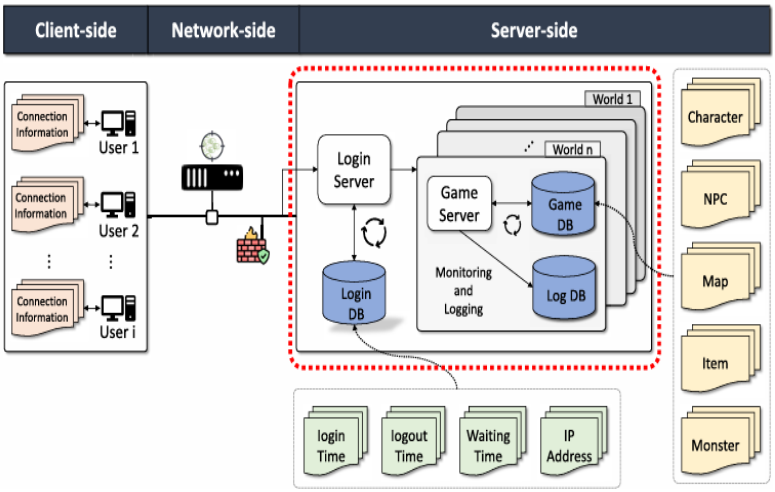


Figure 2. Structure and logic of a stateful game server in MMORPGs [15].

Consequences of Cheating on Stateful Servers
Cheating severely disrupts fair play and can lead to the mass withdrawal of honest players, negatively affecting the in-game economy and developers' revenue. Widespread bot usage and resource exploitation can destabilize the virtual economy, devaluing certain items or flooding the market with illegally obtained assets. Moreover, attacks like DDoS (Distributed Denial of Service) can disrupt game servers, cause lag, and reduce the overall quality of gameplay for all users. Cheating involving account theft and abuse of Real Money Trading (RMT) poses a threat to player security and can result in financial loss.

Cheating Detection Techniques on Stateful Servers
Several methods are employed to detect cheating, including:

- Behavioral analysis of players – Identifying atypical movement patterns, unusually high combat efficiency, or irregular transactions that suggest bot usage or cheating.
- Anomaly detection through log analysis – Servers record all player interactions, and systems can flag suspicious activities like rapid resource accumulation or illogical transactions.
- Network data protection and encryption – Filtering network traffic can block packet manipulation attempts and SQL injection attacks.
- Machine learning – Models trained on normal and abnormal player behavior can identify bots, RMT transactions, and illegal activity.
- CAPTCHA tests and user verification – These help prevent automated scripts and bots from performing tasks in place of real players.

An effective combination of these methods helps maintain game balance, improves server security, and enables a fair experience for all players.

4. Development of the Software Solution

Detecting and preventing memory manipulation-based cheating in MMOGs presents a major challenge for developers and researchers. This phase includes the development and testing of a prototype system designed to detect and prevent memory tampering. The following programming languages and tools were used:

- C++ – for client-side memory monitoring,
- SQL (SQLite, PostgreSQL) – for storing user and detection data,
- REST API (Node.js, Express) – for communication between client and server.

The proposed cheating detection and prevention system for MMOGs is based on a combination of server-side validation, anomaly detection, and security protocols. The goal is to ensure that cheaters cannot easily alter in-game values, while minimizing the rate of false positives. The system is designed around three key security levels:

1. Server-side data validation. Key game parameters - including player health, resource count, and in-game location - are stored and validated server-side to prevent manipulation of local data on the client's machine. This mechanism prevents cheaters from altering gameplay-critical values locally.
2. Anomaly detection. The system uses machine learning algorithms to identify suspicious player behavior. For example, if a player scores an unusually high number of hits in a short time or teleports between game locations, the system flags the behavior as potentially cheating.
3. Use of security protocols. TLS encryption is applied to communication between client and server to protect data from interception and tampering. Additionally, the system uses hashing mechanisms to verify game file integrity and detect unauthorized changes to the game's memory.

Figure 3 illustrates the architecture of the implemented system for detecting and preventing memory manipulation-based cheating. It includes server-side data validation, player behavior anomaly analysis, and cryptographic memory protection methods.
The figure shows how player data is stored and verified, and how unauthorized modifications are detected in real time.

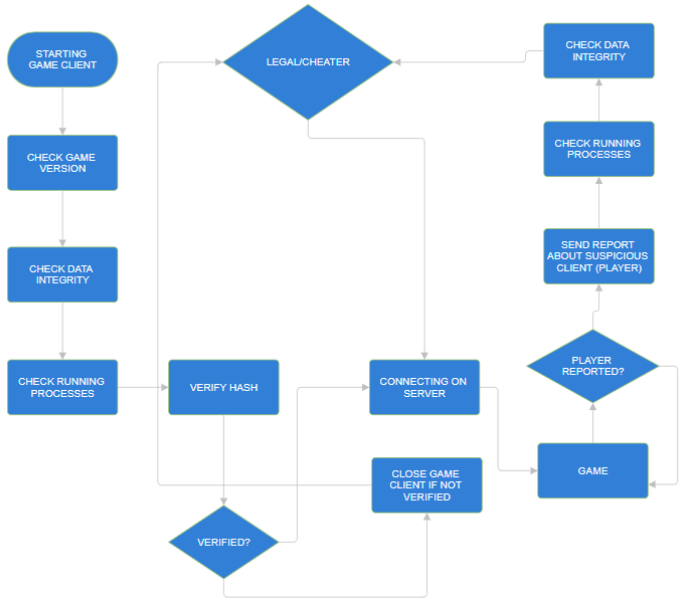


Figure 3. Security measures against memory manipulation in MMOGs.

The clients table schema enables tracking of all active players, their authentication, as well as regular checks for unauthorized modifications to game files.

```
CREATE TABLE clients (
  client_id INTEGER PRIMARY KEY AUTOINCREMENT,
  unique_id TEXT NOT NULL,
  hash_value TEXT NOT NULL,
  last_verified DATETIME NOT NULL,
  violation_count INTEGER DEFAULT 0
);
```

For the purpose of client-side protection and detection of active processes, an additional security layer was implemented on the client side to monitor running processes and detect the presence of cheating tools such as Cheat Engine or memory modification programs. The code implemented in C++ enables the detection of suspicious processes:

```
bool isProcessRunning(const std::string & processName){
  DWORD processList[1024], processCount;
Enum Processes(processList, sizeof(processList), &processCount);
  processCount /= sizeof(DWORD);
for (unsigned int i = 0; i < processCount; ++i) {
    HANDLE processHandle = OpenProcess(PROCESS_QUERY_INFORMATION | PROCESS_VM_READ, FALSE,
processList[i]);
if (processHandle) {
char processNameBuffer[MAX_PATH];
GetModuleBaseNameA(processHandle, nullptr, processNameBuffer, sizeof(processNameBuffer));
if (processName == processNameBuffer) {
        CloseHandle(processHandle);
return true;
      }
      CloseHandle(processHandle);
    }
  }
return false;
}
```

This code segment continuously monitors active processes and identifies memory manipulation programs. When such a process is detected, the player may be automatically disconnected from the session, and a warning is sent to game administrators for further review. The proposed solution utilizes three key layers of security:

- Server-side data validation – all critical game parameters such as player health, resources, and location are verified on the server.
- Anomaly detection – player behavior patterns are analyzed to identify deviations from normal gameplay.
- Use of security protocols – TLS encryption is applied to protect communication between client and server.

The implementation of a database in the cheat detection and prevention system is essential for monitoring players and their activities. The database enables user data storage, game integrity tracking, and suspicious activity detection. Key aspects of the database implementation include:

- Player data storage – each player is assigned a unique identifier used for authentication and activity validation within the game.
- Game file hash value tracking – the system periodically checks file integrity to detect unauthorized modifications.
- Logging of verification timestamps – allows tracking of the last performed security checks.
- Detection of multiple manipulation attempts – if a player repeatedly tries to modify game memory, the system may automatically suspend their account or notify administrators.

The implemented database in the cheat detection and prevention system tracks players and their activities and enables user data storage, where the database fields represent:

- client_id – the unique identifier of the player,
- unique_id – the user identifier used for authentication,
- hash_value – the hash value of game files, used for detecting modifications,
- last_verified – the last date and time the player passed a security check,
- violation_count – a counter tracking the number of unauthorized modification attempts.

Data verification mechanism

The system uses queries to periodically scan the database and identify suspicious players. Example of an SQL query to retrieve users with multiple cheating attempts:

```
SELECT unique_id, violation_count FROM clients WHERE violation_count >3;
```

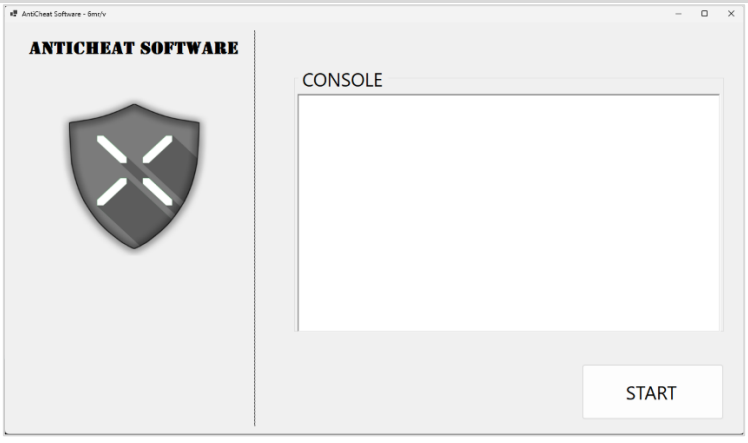


Figure 4. Graphical User Interface of the Application (Anti-Cheat System).

If the number of cheating attempts exceeds a predefined threshold, the system can automatically block the player's access to the game or generate a report for administrators.

Developed GUI Application with Integrated Mechanism

Figure 4 shows the graphical user interface of the application where the previously mentioned mechanism is implemented and integrated.

The interface of the developed anti-cheat system includes a button labeled "START," which, when activated, initiates the anti-cheat mechanism. Additionally, there is a richTextBox component that functions as a real-time text console. This console dynamically displays key information and status messages during system operation (Fig. 5), including processes such as establishing a connection with the server, verifying the user device's memory space, confirming the successful start of the anti-cheat module, and connecting the player to the target server.

This display allows transparent monitoring of the anti-cheat module's activities and represents an important part of evaluating its functionality in the experimental environment.

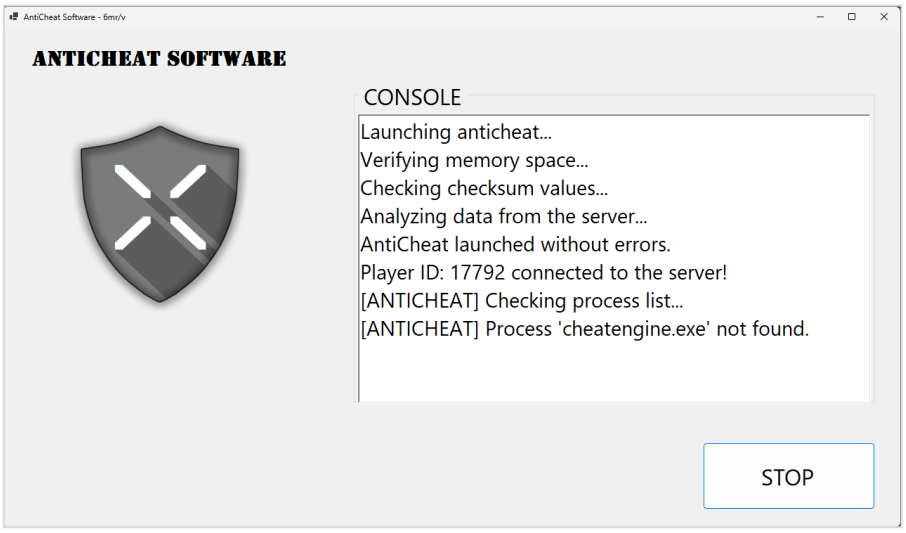


Figure 5. Displaying status messages during system operation.

5. Experimental Testing and System Evaluation

Developed software solution is tested through simulation of real cheating scenarios in the game:

- Test environment setup:
  - Implementation of the security system in a multiplayer game
  - Simulation of attacks (e.g., using Cheat Engine, code injection)
  - Observation of the system's reaction to unauthorized modifications
- Performance metrics:
  - Percentage of successful cheat detection
  - System response time to memory manipulation
  - System load (CPU, RAM, network requirements)
- Analysis of false positives and false negatives

To evaluate the effectiveness of the proposed cheat detection and prevention system, experiments were conducted using simulated cheating scenarios in real playing conditions. Testing covered detection performance analysis, cheat identification through memory manipulation, and analysis of the impact of security protocols on gameplay experience.

5.1 Testing Methodology

Experiments were conducted on a sample of 10 test sessions, where test users applied various memory manipulation techniques to assess the efficiency of the cheat detection system. Tests were performed in a

controlled environment on a simulated multiplayer server, enabling precise data analysis and system response to unauthorized changes in game memory.

For this experiment, the following tools and custom scripts were used:

- Cheat Engine script for modifying memory values, enabling direct modification of in-game memory (e.g., health increase, infinite ammo, teleportation).
- DLL injector for dynamic modification of the game process, injecting custom code into the game to allow unauthorized changes.
- Network packet modification script, intercepting and altering data between client and server to simulate illicit player actions.
- Memory scanner with automatic value patching, automating the process of finding and modifying memory values during gameplay.

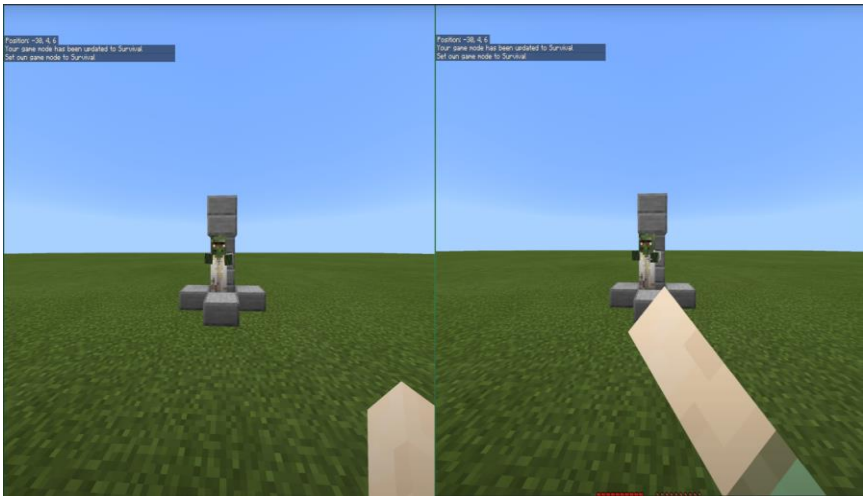


Figure 6. Attempt to attack the enemy character (NPC).

These scripts enabled realistic system testing in scenarios where players used various cheating methods to gain unfair advantages. Experiments included a sample of 50 test sessions where cheaters employed tools like Cheat Engine and custom memory modification scripts. Tests were performed in a controlled environment on a simulated multiplayer server, allowing precise data analysis. Figure 6 documents an attack attempt on an enemy NPC during testing within the game's virtual environment. The attack was initiated from coordinates (-30, 4, 6), but did not result in a successful hit. System behavior analysis shows that the distance between the player and the target NPC exceeded the allowed hitbox or attack range defined by game rules. This detection and registration of an unsuccessful attack confirms the accuracy and reliability of the implemented protection, representing an important aspect of verifying combat system behavior under real test conditions.

After the initial test, a memory space analysis was conducted to identify the address responsible for the attack range parameter. Using Cheat Engine, a specific memory location controlling the maximum distance for interaction between the player and enemy NPCs was located. This value was modified to artificially extend the attack range, enabling attacks on targets beyond the standard range defined by game rules. The result of this modification is shown in Figure 7 and represents an important step in evaluating potential security vulnerabilities of the system in the context of client-side manipulations.

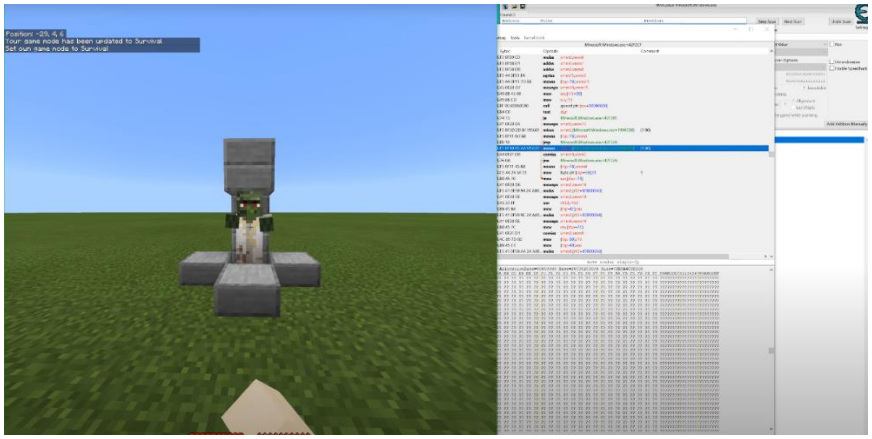


Figure 7. Modification of local memory on the client side.

Figure 8 documents the test result after modifying the memory location responsible for the attack range. The attack was again initiated from the same coordinates (-30, 4, 6), which in the previous attempt was outside the allowed range. This time, thanks to the modified value in the client's memory, the attack was successfully executed and contact with the target NPC was recorded. The image clearly shows the activation of the animation in the form of a red color appearing on impact, serving as visual confirmation that the attack was detected and correctly registered in the game. This experiment confirms that unauthorized modification of client memory can bypass the attack range limitation defined by the game rules.

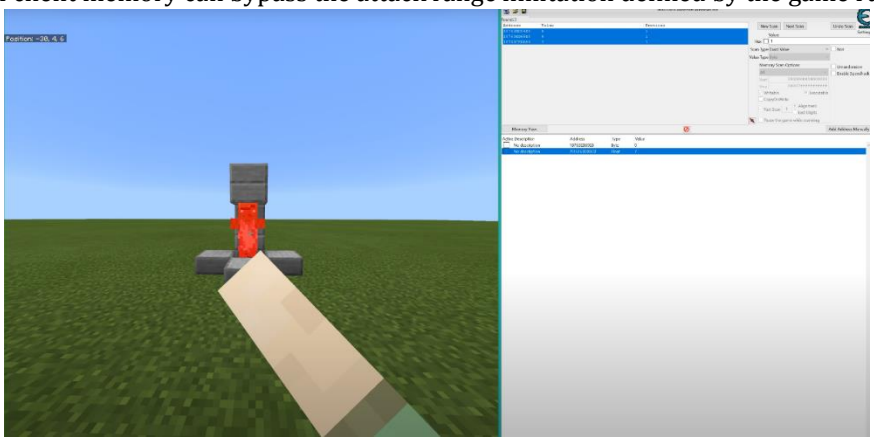


Figure 8. Attempted attack on the enemy character after memory modifications.

After confirming the experiment and successfully simulating an attack by modifying the range, the next phase involves testing the cheat detection results, aiming to verify whether the anticheat system adequately recognizes and responds to unauthorized changes in the client's memory space.

Results of cheat detection

During the testing of the anti-cheat system, a total of 50 simulated cheating attempts were performed, spread across various methods and scenarios. Of these, 70% of attempts (35 cases) involved direct code injection into the game process, while the remaining 30% (15 cases) included more sophisticated techniques such as real-time memory modification and hooking of system functions. The system successfully detected all cheating attempts thanks to a combination of automated security mechanisms and manual player reports through the /report command. These results confirm that the system can effectively respond to a variety of unauthorized behaviors regardless of the cheating technique used.

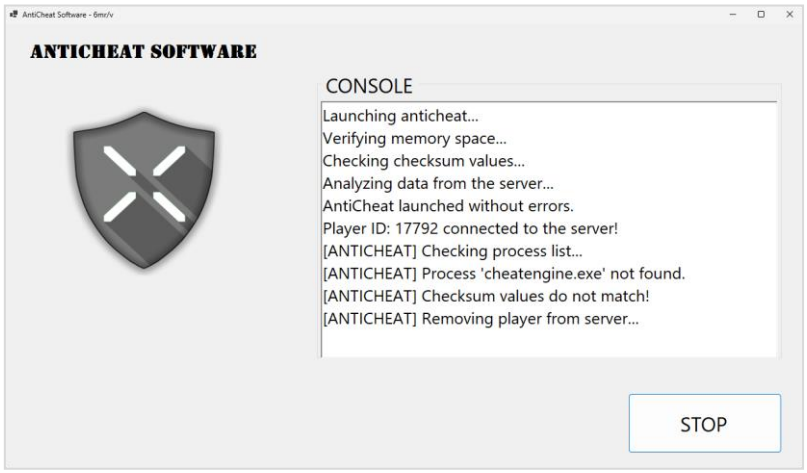


Figure 9. Status messages output in the anti-cheat software.

Figure 9 documents the successful detection of unauthorized modification by the anti-cheat system. During integrity verification, the system compared the checksum values of the active memory space of the client application with the reference values of the original files. A mismatch was detected, clearly indicating manipulation of memory content - specifically, a change in attack range. As a result of this detection, the anti-cheat automatically triggered the procedure to remove the player from the server, preventing further gameplay under irregular conditions. Figure 10 shows the ban message notifying the player of the reasons for exclusion, confirming the protective system's functionality and its ability to respond timely to cheating attempts.

Experimental testing of the anti-cheat system was conducted over multiple sessions, focusing on detecting unauthorized code injection within the game process. The system successfully identified all cheating attempts by combining automated detection with user reports.

Testing was carried out through 50 separate sessions where players tried various code injection methods, including:

- DLL file injection,
- Hooking game functions,
- Modifying the application's execution flow.

In all sessions, the system successfully detected cheating attempts:

- 70% of code injection attempts were automatically identified through system mechanisms monitoring process integrity and memory anomalies.
- 30% of attempts were recognized through manual player reports using the /report command, after which the server performed additional verification and confirmation.

During the experiment, the detection success rate for injected code was 100% across all tested cases. Automated detection mechanisms enabled system reaction within an average time of 0.42 seconds, while player-reported cheating via the /report command was processed within 1 to 3 seconds, depending on current server load.

No false positives were recorded during testing, indicating high reliability and accuracy of the system. Additional network latency caused by security checks averaged only 4 milliseconds per case, which did not noticeably affect gameplay flow or user experience.

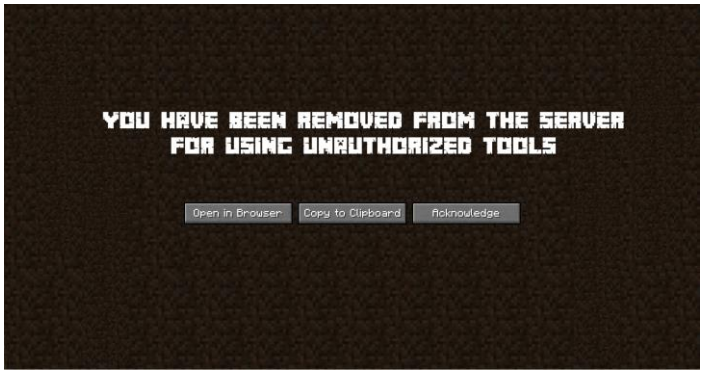


Figure 10. Notification message about the reasons for disconnection from the server.

5.2 Performance analysis

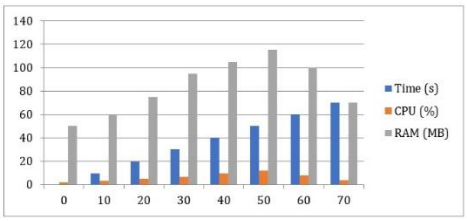
The anti-cheat software is designed to efficiently handle client requests even under a high number of simultaneous players. During testing with up to 200 virtually simulated clients, the average server request processing time was 42 milliseconds, maintaining stable latency below 180 ms.

CPU usage remained under 70% with 200 clients, while RAM consumption grew linearly, reaching 700 MB at peak load. Thanks to an optimized asynchronous request processing model and efficient memory usage, no significant slowdowns or data loss occurred under heavy load.

The system supports horizontal scaling, allowing capacity expansion if needed. Additionally, the introduction of a basic throttling mechanism and caching reduces the risk of server congestion during unexpected spikes in request volume.

Figure 11 presents a graphical overview of all anti-cheat system test results, organized by types of cheating attempts and their detection methods. The chart shows the distribution of 50 test sessions, including methods such as DLL injection, game function hooking, and execution flow modification. It is evident that 70% of attempts were detected automatically through integrated memory integrity monitoring and system anomaly mechanisms, while 30% were identified via user reports using the /report command, followed by additional server-side validation.

Time (s)	CPU (%)	RAM (MB)	Description
0	2	50	Anti-cheat software launching
10	3	60	Entering the game
20	5	75	Normal operation
30	7	95	Cheat tool launched
40	10	105	Detection active
50	12	115	Scanning memory
60	8	100	Cheat disabled
70	4	70	System stabilizing



Number of clients	Requests per minute	CPU usage (%)	RAM usage (MB)	Latency (ms)	Note
5	5	2	80	30	Normal operation
10	20	5	100	35	Minimal load
15	15	8	130	40	OK
30	40	12	180	50	Latency increase starting
50	50	25	300	80	Slight slowdown
100	200	45	480	120	Higher load

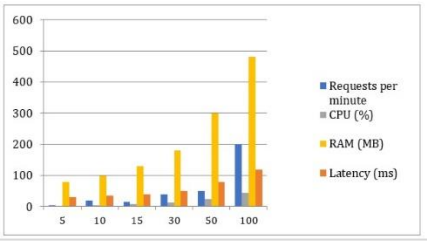


Figure 11. Graphic display of the results of all performed tests.

The graph also illustrates the system's response time, where automatic detection takes on average 0.42 seconds, while response times to user reports varied from 1 to 3 seconds depending on the server load. Additionally, it shows system performance under increased player counts, maintaining stable CPU usage (below 70%) and linear RAM consumption growth (up to 700 MB with 200 simultaneous clients), without negatively affecting latency or server stability. This graph provides a clear and quantitative confirmation of the tested anti-cheat system's efficiency and scalability in realistic simulation conditions.

6. Conclusion

Theoretical analysis of cheating in massively multiplayer online games (MMOGs) has shown that memory manipulation is one of the most common and dangerous methods of cheating, as it allows users to gain unfair advantages in the game. This type of cheating disrupts the game balance, violates fair play principles, and directly affects the experience of other players, potentially leading to a loss of user trust and active players. The most common tools and techniques, such as Cheat Engine, which operate at the RAM memory level and bypass traditional security mechanisms, have been identified. Furthermore, existing approaches to cheat detection were analyzed, highlighting the need for efficient and flexible software solutions capable of operating in real time.

Empirical research conducted within this work confirms that the developed software solution effectively detects and blocks attempts at memory manipulation. Testing demonstrated that the system successfully recognizes unauthorized changes to in-game memory variables and automatically responds by suspending the game and logging the incident. The implementation of a combined client-server model enabled synchronized operation of protective mechanisms at both levels, significantly reducing the potential for abuse. The system is capable of operating in real time with minimal impact on game performance, making it suitable for integration into various MMOG platforms. Additionally, the system's logical structure allows for upgrades and the introduction of machine learning mechanisms to identify patterns of suspicious behavior. These results indicate great potential for improving security in online games, and the conclusions of this work can serve as a foundation for future research and the development of more sophisticated anti-cheat systems. This confirms that the fight against cheating is not only a technical challenge but also a crucial element in preserving the integrity and long-term sustainability of MMOG communities.

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Catalan Numbers in Sporting Events

Šejla Jusić Gerzić[1], Fatka Kulenović[1] and Namira Krupić[2]

[1] Faculty of Technical Engineering, University of Bihać, Bihać, Bosnia and Herzegovina
[2] Electrical Engineering High School Bihać, Bihać, Bosnia and Herzegovina

E-mail: sejla.jusic@unbi.ba

Abstract Catalan numbers are one of the most famous sequences in mathematics and have applications in combinatorics, algebra, number theory, graph theory, cryptography, etc. This paper explores the application of Catalan numbers in sports events based on the principle of "best of 2n-1 sets". We will derive a formula to calculate the expected number of sets to be played. The implementation of the algorithm will be performed in the C++ programming language, with analysis on specific data.

Key words. Catalan numbers, Sport events, C++

1. Introduction

Catalan numbers represent one of the most well-known sequences in mathematics. They appear in many branches of mathematics, such as combinatorics, algebra, number theory, graph theory, cryptography, etc. Leonhard Euler (1707–1783), a Swiss mathematician, physicist, and astronomer, in a letter to the Prussian mathematician Christian Goldbach (1670–1764) in 1751 asked the question of how many ways a convex polygon can be divided into triangles. This is the so-called problem of triangulation of a convex polygon. Euler was the first to come up with a general expression for the number of triangulations, and later presented this problem to the Hungarian mathematician Johann Andreas von Segner (1704–1777), who then came up with a recursive relation for the number of triangulations. On the other hand, the French mathematician, physicist, and engineer Gabriel Lamé (1795–1870) was the first to present a combinatorial proof of the results obtained by Euler and von Segner. His proof was later discussed and developed by the Belgian mathematician Eugené Charles Catalan (1814–1894). Catalan also derived and proved many important properties of these numbers. It is in his honor that these numbers are called Catalan numbers [3].

1.1 Definition and basic properties of Catalan numbers

Definition 1 Catalan numbers represent a series of natural numbers C_n that satisfy the recurrence relation

$$C_n = \sum_{i=0}^{n-1} C_i C_{n-i-1}, \quad C_0 = 1. \qquad (1)$$

Using recursion (1), we can easily calculate the first few Catalan numbers, which are listed in Table 2.

Table 2 The value of the first few Catalan numbers.

n	0	1	2	3	4	5	6	7	8	9	10	11
C_n	1	1	2	5	14	42	132	429	1 430	4 862	16 796	58 786

There are also many other properties of Catalan numbers that can be used to compute them. We will present these properties in Theorem 1.

Theorem 1 [2] Catalan numbers C_n satisfy

1. the relations

$$C_n = \binom{2n}{n} - \binom{2n}{n-1}, \qquad C_n = \frac{1}{n+1}\sum_{i=0}^{n}\binom{n}{i}^2, \qquad (2)$$

2. the nonlinear recurrence relation

$$C_{n+1} = \frac{2(2n+1)}{n+2}\,C_n, \;\; C_0 = 1, \qquad (3)$$

3. asymptotic expression

$$C_n \Big/ \left(\frac{4^n}{\sqrt{\pi}n^{3/2}}\right) \to 1 \text{ as } n \to \infty. \qquad (4)$$

Formulas (2), (3) and (4) listed in Theorem 1, and other formulas which can be found in [1], [2] and [3] can be applied when implementing Catalan numbers in various programming languages.

1.2 Problems related to Catalan numbers

The problem of triangulating a convex polygon led to the discovery of Catalan numbers. To triangulate a regular n-gon, we need to draw $n-3$ non-intersecting diagonals, thus dividing it into $n-2$ triangles. It can be easily shown that the number of ways to do this is equal to C_{n-2}. So, for example, we can triangulate a regular hexagon in C_4, i.e. in 14 ways.

Multiplication is a binary operation, so n given natural numbers are multiplied by first multiplying two numbers, then their product with the next number, until all numbers have been multiplied. It is shown that there are C_{n-1} ways to multiply n numbers without changing the order of the numbers, only the order of multiplication.

In graph theory, C_n represents the number of ordered trees with $n+1$ vertices, the number of binary trees with n vertices, and the total number of complete binary trees with $2n+1$ vertices.

Dyck's path is a path that starts at the point $(0,0)$ and ends at the point $(2n, 0)$ and goes either one step diagonally from southwest to northeast or one step from northwest to southeast. The number of Dyck paths of length $2n$ ending on the horizontal axis is equal to C_n [3].

These are some of the main applications of Catalan numbers, but unexpectedly, Catalan numbers also appear in the expected number of sets that will be played in competitions based on the "best of $2n-1$ sets (games)" principle [1].

2. Catalan numbers in sporting events

Let's consider a competition between two players (or teams), A and B, where the winner is the first to win n out of a total of $2n-1$ games (sets). This format is commonly used in sports like tennis (e.g., Grand Slam, Davis Cup), volleyball (e.g., Olympic Games, World Championship), baseball (e.g., American League Championship Series, League Championship Series), basketball (NBA), etc.

Let p be the probability that team A wins a game (set). Then, the probability that team B wins is $1 - p = q$. Let E_n be the expected number of games (sets) played until one of the teams wins the competition, meaning that one team wins n out of at most $2n-1$ games (sets).

E_1 represents the expected number of sets that can be played for a team to win a competition, i.e. to win one of at most one $(2 \cdot 1 - 1 = 1)$ set. The probability that team A wins is p, and that team B wins is q. Then $E_1 = 1 \cdot (p+q) = 1$.

Next, E_2 is the expected number of sets that can be played for a team to win a competition, i.e. to win two out of a maximum of three $(2 \cdot 2 - 1 = 3)$ sets. It can happen that two sets are played, with either team A or team B winning. The probability that team A wins two sets is p^2, and team B is q^2. The probability that two sets will be played is $p^2 + q^2$. If three sets are played, then in order for team A to win competition, it must win the third set, and have one loss and one win in the first two sets. The probability that team A wins in this way is $2p^2\,q$, and that team B wins is $2pq^2$. The probability that three sets will be played is $2p^2q + 2pq^2$. Therefore, the expected number of sets that can be played to have a winner is $E_2 = 2(p^2+q^2) +$

$3(2p^2\,q + 2pq^2)$. This can be written as $E_2 = 2(p^2 + q^2) + 6pq(p + q) = 2(p^2 + q^2 + 3pq) = 2(1 + pq)$, because
$p + q = 1$.

Let us now determine E_3, i.e. the expected number of sets to be played for one of the teams to win three out of a maximum of five $(2 \cdot 3 - 1 = 5)$ sets. It may happen that three sets are played in which either team A or team B wins. The probability that team A wins in three sets is p^3, and the probability that team B wins in all three sets is q^3. Therefore, the probability that three sets will be played is $p^3 + q^3 = p^2 - pq + q^2 = 1 - 3pq$. If four sets are played and team A wins, then team A must win in the last, fourth, set, and must have two wins and one loss in the first three sets. The probability that team A wins in this way is $3p^3q$, and that team B wins is $3pq^3$. The probability that four sets are played is $3p^3q + 3pq^3 = 3pq(p^2 + q^2\,) = 3pq(1 - 2pq)$. If five sets are played, then in order for team A to win, it must win the last, fifth, set, and in the first four sets it must have two wins and two losses. The probability that team A wins in five sets is $\binom{4}{2}p^3q^2$, i.e. $6p^3q^2$. Analogously, the probability that team B wins is $6p^2q^3$. Therefore, the probability that five sets will be played is $6p^3q^2 + 6p^3q^2 = 6p^2q^2$. Let us now determine E_3 , i.e. the expected number of sets that can be played for one of the teams to win three, out of a maximum of five sets

$$E_3 = 3(1 - 3pq) + 12pq(1 - 2pq) + 30p^2q^2,$$

that is $E_3 = 3(1 + pq + 2p^2q^2)$.

In a similar way, we conclude that $E_4 = 4(1 + pq + 2p^2\,q^2 + 5p^3\,q^3)$.

Let's look at the differences $\frac{E_{n+1}}{n+1} - \frac{E_n}{n}$. Based on the previously calculated values, we see

$$\frac{E_2}{2} - \frac{E_1}{1} = pq, \qquad \frac{E_3}{3} - \frac{E_2}{2} = 2p^2q^2, \qquad \frac{E_4}{4} - \frac{E_3}{3} = 5p^3q^3, \ldots \qquad (5)$$

Based on relations (5), we can assume that that the relation $\frac{E_{n+1}}{n+1} - \frac{E_n}{n} = C_n\,p^nq^n$, i.e.

$$\frac{E_{n+1}}{n+1} = \frac{E_n}{n} + C_np^nq^n \qquad (6)$$

is valid.

To prove relation (6), we will consider E_n, i.e., the expected number of sets that can be played for a team to win in n out of at most $2n - 1$ sets. The probability that n sets were played is $p^n + q^n$, because the probability that team A won all n sets is p^n, and the probability that team B won all n sets is q^n. If $n + 1$ games (sets) were played with the winner A, then in the last set, team A won, and in the first n sets, there was one loss for team A. The probability that $n + 1$ games were played with a winner A is then $\binom{n}{1}p^nq$, and the total probability that $n + 1$ sets were played is $\binom{n}{1}(p^nq + q^np)$. If $n + 2$ sets were played with a winner A, then in the last set, team A won, and in the first $n + 1$ sets, there were two losses. The probability that $n + 2$ sets were played is $\binom{n+1}{2}(p^nq^2 + p^2q^n)$. In a similar way, we conclude for $n + 2, n + 3, \ldots, 2n - 1$. Now, we have

$$E_n = \sum_{i=0}^{n-1}(n + i)\binom{n + i - 1}{i}(p^nq^i + p^iq^n). \qquad (7)$$

Since, $\binom{n + i - 1}{i} = \frac{(n+i-1)!}{i!\cdot(n-1)!} = \frac{n}{n+i} \cdot \frac{(n+i)!}{i!\cdot n!} = \frac{n}{n+i}\binom{n + i}{i}$, from relation (7) we conclude that

$$\frac{E_n}{n} = \sum_{i=0}^{n-1}\binom{n + i}{i}(p^nq^i + p^iq^n). \qquad (8)$$

Therefore, the relation (8) for $n + 1$ becomes

$$\frac{E_{n+1}}{n + 1} = \sum_{i=0}^{n}\binom{n + i + 1}{i}(p^{n+1}q^i + p^iq^{n+1}). \qquad (9)$$

Since $p + q = 1$, we can write (8) as

$$\frac{E_{n+1}}{n+1} = \sum_{i=0}^{n} \binom{n+i+1}{i} (p^n q^i + q^n p^i) - \sum_{i=0}^{n} \binom{n+i+1}{i} (p^n q^{i+1} + q^n p^{i+1}). \quad (10)$$

Since, $\binom{n+i+1}{i} = \frac{(n+i+1)!}{i!\cdot(n+1)!} = \left(1 + \frac{i}{n+1}\right) \cdot \frac{(n+i)!}{i!\cdot n!} = \binom{n+i}{i} + \binom{n+i}{i-1}$, where $\binom{n}{-1} = 0$, we can write relation (10) as

$$\frac{E_{n+1}}{n+1} = \sum_{i=0}^{n} \binom{n+i}{i} (p^n q^i + p^i q^n) + \sum_{i=1}^{n} \binom{n+i}{i-1} (p^n q^i + p^i q^n) - \sum_{i=1}^{n+1} \binom{n+i}{i-1} (p^n q^i + p^i q^n) \quad (11)$$

Therefore, it is

$$\frac{E_{n+1}}{n+1} = \sum_{i=0}^{n} \binom{n+i}{i} (p^n q^i + q^n p^i) - \binom{2n+1}{n} (p^n q^{n+1} + q^n p^{n+1}), \quad (12)$$

or

$$\frac{E_{n+1}}{n+1} = \sum_{i=0}^{n-1} \binom{n+i}{i} (p^n q^i + p^i q^n) + \binom{2n}{n} (p^n q^n + p^n q^n) - \binom{2n+1}{n} p^n q^n (p+q). \quad (13)$$

Since je $p + q = 1$ and because of (8) relation (13) becomes

$$\frac{E_{n+1}}{n+1} = \frac{E_n}{n} + \left[2\binom{2n}{n} - \binom{2n+1}{n}\right] p^n q^n. \quad (14)$$

It is easy to show that $2\binom{2n}{n} - \binom{2n+1}{n} = \binom{2n}{n} - \binom{2n}{n-1}$, so based on Theorem 1 the relation (6) is shown. As a result we have

$$\begin{aligned} \frac{E_2}{2} &= \frac{E_1}{1} + C_1 p^1 q^1 = C_0 p^0 q^0 + C_1 p^1 q^1, \\ \frac{E_3}{3} &= \frac{E_2}{2} + C_2 p^2 q^2 = C_0 p^0 q^0 + C_1 p^1 q^1 + C_2 p^2 q^2, \\ \frac{E_4}{4} &= \frac{E_3}{3} + C_3 p^3 q^3 = C_0 p^0 q^0 + C_1 p^1 q^1 + C_2 p^2 q^2 + C_3 p^3 q^3 \ldots \end{aligned} \quad (15)$$

By analogy, we conclude that $\frac{E_n}{n} = \sum_{i=0}^{n-1} C_i p^i q^i$, i.e.

$$E_n = n \sum_{i=0}^{n-1} C_i p^i q^i. \quad (16)$$

2.1 Example

At Wimbledon, the tennis player who wins in 3 sets wins. It is clear that a maximum of 5 sets can be played. Let tennis players A and B compete at Wimbledon. Let the probability that tennis player A wins the set be 0,65. Then the probability that tennis player B will win is 0,35. Using relation (16) the expected number of sets to be played is

$$E_3 = 3(1 + C_1 pq + C_2 p^2 q^2) = 3(1 + 1 \cdot 0{,}65 \cdot 0{,}35 + 2 \cdot 0{,}65^2 \cdot 0{,}35^2) = 3{,}99.$$

The American League Championship Series (ALCS) is a best of seven playoffs, meaning two teams play until one team wins in 4 games. Let two baseball teams A and B compete at ALCS. Let the probability that team A wins the game be 0,6. Then the probability that team B will win is 0,4. The expected number of games to be played is

$$E_4 = 4\sum_{i=0}^{3} C_i p^i q^i = 4(1 + 1 \cdot 0{,}6 \cdot 0{,}4 + 2 \cdot 0{,}6^2 \cdot 0{,}4^2 + 5 \cdot 0{,}6^3 \cdot 0{,}4^3) = 5{,}697.$$

3. Implementation of the example in the C++ programming language

We will implement a program that, for the entered value n, will calculate the expected number of sets (games) that will be played in order for one of the competing teams to win the competition, i.e. to win n of at most $2n - 1$ games. We will use Dev-C++ as our programming environment. It is a free development environment for programming in C and C++.

The function to calculate the expected number of sets is given in Figure 4. Code for expected number of sets to be played

```
double expectedNumber (int n, double p)
{
    vector<long long> cat(n+1,0);
    cat[0]=1;
    cat[1]=1;
    double res=1;
    if(n==1)
        res=1;
        else
        {
         for (int i=2; i<=n; i++)
            {
                for(int j=0; j<i; j++)
                {
                    cat[i]+=cat[j]*cat[i-j-1];
                }
                res=res+cat[i-1]*pow(p,i-1)*pow(1-p,i-1);
            }
         res=n*res;
        }
    return res;
}
```

Figure 4. Code for expected number of sets to be played.

The program output for $n = 3$ and $p = 0{,}65$ is given in Figure 5.

```
Enter the number of sets (games) the player (team) must win to win a competition
3
Enter the probability that a player (team) will win the set (game).
0.65
Expected number of sets (games) to be played is 3.99304
```

Figure 5. Displaying the solution of the first example.

The program output for $n = 4$ and $p = 0{,}6$ is given in Figure 6.

```
Enter the number of sets (games) the player (team) must win to win a competition
4
Enter the probability that a player (team) will win the set (game).
0.6
Expected number of sets (games) to be played is 5.69728
```

Figure 6. Displaying the solution of the second example.

4 Conclusion

In this paper, Catalan's numbers and their application in certain sports events are analyzed. Namely, we observe games that are played on the "best of $2n - 1$" principle. The game will be won by the player who has n wins. It is clear that no more than $2n - 1$ games (sets) will be played, and the expected number of sets can be expressed using Catalan numbers. The implementation of the algorithm in the C++

programming language proved to be efficient, enabling a quick solution to this problem. In conclusion, we see how by applying combinatorics and probabilities, we can apply mathematical models in the calculation of sets in sports events such as, for example, Grand Slam, Davis Cup tournaments etc.

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The design of a computer programme used for the measurement of the fractal dimension within a digital image using the Python programming language

Adnan Dizdarević and Kristina Vinčar

University of Bihać, Faculty of Technical Engineering, Bosnia and Herzegovina

E-mail: adnandiz21@gmail.com

Abstract. In mathematics, fractals are geometric forms of extremely irregular shapes where parts of it are similar to each other regardless of size and position, and are known to exist in both small and large-scale objects of same type in nature, such as snowflakes and flakes of ice under a microscope. Coined as a term in 1975 exactly to define such phenomena, the word fractal comes from the Latin word fractus which means to shatter, aka break down into small particles. Fractals possess certain idiosyncratic features, the most unique one being the fractal dimension, which describes the density of a Fractal in a specific n-dimensional space. Of course being one of, if not the most important feature of a fractal set, there are a multitude of methods to measuring the fractal dimension, one of the most popular (and easiest methods) is the box counting dimension. Due to its relative simplicity, the box-counting dimension is easy to implement within any programming language, however due to the necessity of creating an easy to use software application the programming language Python was used. Python has been an extremely robust and highly represented programming language for some time now, with a lot of libraries that assist developers with creating fast solutions to existing problems, and in this example was used to create a graphical user interface that would allow users to very easily calculate the fractal dimensions of any amount of fractal sets stored within digital images in a specific folder on their computers. With this goal in mind, Python has proven itself as the best option for creating such an easy to use graphical user interface for this programme as well as any other similar programs.

1. Introduction

Benoit Mandelbrot, sources state that, although he was a mathematician, his non-specific education, conditioned by frequent relocations and sheltering from the horrors of the Second World War, shaped him in such a way that his mathematical thinking followed his internal logic more than the usual mathematical patterns of the time. Perhaps it is precisely because of these "vagueness" that Mandelbrot introduces the idea of fractals into the world of mathematics, and describes them as shapes that contain smaller variants of themselves. This recursive description was not at first acceptable to the mathematical community at the time, but it laid the foundation for a new way of thinking. Almost two decades later, the British mathematician Kenneth Falconer used the language of mathematics and the Latin principle most quoted among mathematicians that "all roads lead to Rome" to prove certain claims that Mandelbrot had previously made. Since Falconer succeeded in his goal of proving Mandelbrot's theory, using various mathematical methods, the world of mathematics was finally enriched with the concept of fractals, as well as all their mathematical operations, although they were initially rejected. Thanks to Falconer's achievements, extremely complex fractals can now be simplified and operated on, which leads to the fact that they can also be implemented in software, which, considering that programming is a direct product of mathematics, is not surprising. Fractals are used in modern computing on a daily basis, and with the advancements in digital imagery, software and mathematics are closer than ever. Therefore, a program was designed and developed to measure one of the key characteristics of fractals, namely the fractal dimension.

2. The Theory of Fractals

Fractal theory is a relatively new branch of mathematics, specifically geometry, however it does correlate with set theory. Essentially, fractals were "discovered" by Polish-born French-American scientist Benoit

Mandelbrot in the 1970s, whose ideas about fractals were initially perceived as completely superficial and non-mathematical by his peers. This might have been due to their rather vague and over-encompassing definition, which Mandelbrot himself defines as: "a rough or fragmented geometric shape that can be split into parts, each of which is (at least approximately) a reduced-size copy of the whole [3]". A rather vague definition at first, however the same essentially allows for the usage of fractals to describe any and all geometric shapes. Noting how the term *shape* is used, since the only exclusions between fractal and "classical" geometry are single dimensional shapes (lines - segments, rays). More precisely however, fractals have existed more or less since the beginning of humanity, with various sources stating either the renaissance polymath Albert Durer or the Dalmatian polymath Ruđer Bošković as its first discoverers, but Mandelbrot himself notes that the first and biggest collection of fractals comes from the Japanese painter Houkusai Katsushika [1][2][6]. Another point to help in the understanding of this neologism is the name itself, fractal; derived from the Latin verb fractus, which means broken or fractured, which Mandelbrot used to expand on the concept of theoretical fractional dimensions to geometric patterns in nature [3]. These previous definitions and explanations may still be vague enough to consider them a viable source to research and understand fractals, therefore Mandelbrot proposed another approach, categorisation. Which as a form of solution to the sheer overwhelming over-encompassing nature of fractal theory was the right approach. The categorisation is based on two principal factors: the degree of self-similarity and the origin of the fractals creation [3][4][9].

Moreover, these categorisations are also too vague, therefore in 1989 the awarded British mathematician Kenneth Falconer expanded on the previous categorisation; and due to the fact that it has always been troublesome to give one exact definition of fractals, stated fractals should not be categorised strictly, and rather be categorised generally by the gestalt of the following features [4][5][6][7][8]:

- Self-similarity (which can be divided into *Complete self-similarity; Quasi-self-similarity -, Statistical self-similarity, Qualitative self-similarity, Multi-fractal scaling*)
- A smooth or detailed structure on arbitrarily small scales or arbitrarily small orders of magnitude.
- Local and global irregularities that cannot be easily described in the language of traditional Euclidean geometry except as the limit of a recursively defined sequence of phases. For images of fractal patterns, this is expressed by phrases such as "smoothly pilling up surfaces" and "swirls upon swirls".

Falconer's contribution with the previous list of features help in the understanding of fractals along with the definition he gave which is more of a list then a strict definition [4]:

"When we refer to a set F as a fractal, we will typically have the following in mind:

- F has a fine structure, i.e. details on arbitrarily small scales,
- F is too irregular to be described in traditional geometric language, both locally and globally,
- Often F has some form of self-similarity, perhaps approximate or statistical,
- Usually the 'fractal dimension' of F (defined in some way) is larger than its topological dimension,

In most cases of interest, F is defined in a very simple way, perhaps recursively."

The previous statements give an explanation to the most famous fractal, which is the Mandelbrot set (Figure 1.) [4][9].

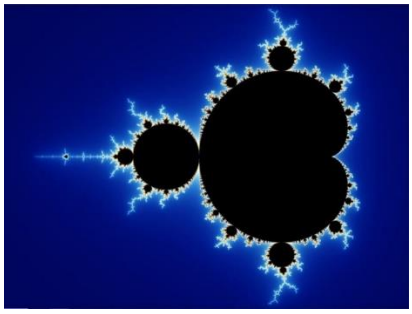

Figure 1. Mandelbrot set.

Many note that Falconer's experience and expertise with set theory aided in the understanding of fractals as a concept by tying fractal theory with set theory. Along with the aforementioned, fractals have another particular descriptor, such as the fractal dimension, which in most cases will be the Hausdorff dimension.

2.1 The Hausdorff measure and Hausdorff dimension

The Hausdorff measure is defined as: the μ function of P(R^n) -> [0; +∞) is a measure of R^n if it satisfies the following properties [4][9]:

μ (Ø) = 0.

μ (A) ≤ μ(B) if $A \subseteq B \subseteq R^n$ (flatness of a measure).

If A_1, A_2, ... is a countable (or a limited) sequence of sets then (1):

$$\mu(\bigcup_{i=1}^{\infty} A_i) \leq \sum_{i=1}^{\infty} \mu(A_i) \quad (1)$$

If a set is decomposed into a countable number of disjoint Borel sets, then the total measure of the parts is equal to the measure of the whole, which is (2):

$$\mu(\bigcup_{i=1}^{\infty} A_i) = \sum_{i=1}^{\infty} \mu(A_i) \quad (2)$$

Also, if all conditions are met, but it happens that set B is a subset of set A (3), set A can be described as a disjoint union, and provided that both sets are Borel sets, it is obvious that the function μ(A/B) is equal to the difference of the functions μ(A) and μ(B), that is (4) [4][9]:

$$A \supset B \quad (3)$$

$$\mu(A/B) = \mu(A) - \mu(B) \quad (4)$$

Similarly if A_1,A_2, A_3 ... is an increasing sequence of Borel sets, then the following conclusion (5) can be made [4]:

$$\lim_{i \to \infty} \mu(A_i) = \mu(\bigcup_{i=1}^{\infty} A_i) \quad (5)$$

More generally, it can be shown if δ > 0, then A_δ are Borel sets that grow as δ becomes smaller (6), that is $A_{\delta'} \subset A_\delta$ for $0 < \delta < \delta'$; then [4]:

$$\lim_{\delta \to 0} \mu(A_\delta) = \mu(\bigcup_{\delta > 0} A_\delta) \quad (6)$$

Using the previously stated, the Hausdorff dimension can be used to define a variant called the s-dimensional Hausdorff measure. Which in fact is also called the Hausdorff dimension (7), and can be calculated if s ≥ 0 for a specific set (e.g. the set X):

$$H^s(X) = \lim_{\delta \to 0} H_\delta^s(X) \quad (7)$$

The limit exists in any subset of X within $\boldsymbol{\mathcal{R}}^n$, but the limiting value itself can be (and usually is) zero and infinity [4]. Also, if a function is increasing and bounded from above in the set $\boldsymbol{\mathcal{R}}$, it must have a limit. If it is not bounded from above in the set $\boldsymbol{\mathcal{R}}$, it has a limit ∞ [9]. Also, $H^s(X)$ is called the s-dimensional measure of X, the s-dimensional measure of the set X, or the s-dimensional measure of the function X [4][9].

Knowing the above, it can be concluded that H^srepresents some measure [4]. The simplest representation of this statement is $H^s(\emptyset) = 0$, and if the Euclidean space E [19] is contained within some function F, then $H^s(E) \leq H^s(F)$, and if $\{F_i\}$ is a countable collection (family) of sets, then it is called the countable stability of the Hausdorff measure (8) [4][9];

$$H^s(\bigcup_{i=1}^{\infty} F_i) \leq \sum_{i=1}^{\infty} H^s(F_i) \quad (8)$$

The measure itself generalizes known ideas about measure, space, volume and the like. It can be shown that for subsets of $\boldsymbol{\mathcal{R}}^n$. The n-dimensional Hausdorff measure is in some constant quotient only the Leber measure [20], that is, an ordinary n-dimensional volume (9). More precisely, if F is a Borel subset of $\boldsymbol{\mathcal{R}}^n$, then:

$$H^n(F) = c_n^{-1} vol^n(F) \quad (9)$$

where c_n represents the volume of an n-dimensional sphere whose diameter is equal to one [4].The previous (9) brings forth the idea of scalability to fractal theory, and since it is already known that scalability of fractals is one of their fundamental features, and is essentially the same for lower dimensions as a *Leber measure*. The scaling ability is therefore analogous to length, area and volume. However, while the length increases with the factor λ, the space with λ^2, and the volume with λ^3 - the s-dimensional Hausdorff measure scales with the factor λ^s (Figure 2.). This ability to scale is fundamental to fractal theory [4].

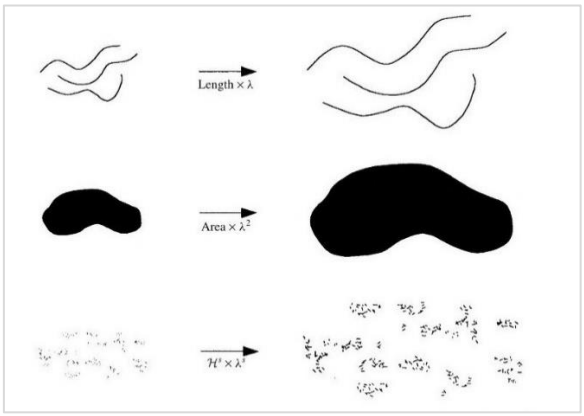

Figure 2. Proof of the scalability of fractals.

Falconer himself proposes to measure the set ignoring irregularities in the size that are smaller than δ for each δ [4], and to monitor the behavior of that measurement as δ tends to zero (δ→0), or as they state: "Let F be a curve on the plane and δ→0, then the measure Mδ(F) represents the number of steps required for a pair of divisor sets of length δ to exceed the size of F as δ→0. Where the constant s serves to represent the divisor dimension of F with s, and the constant c represents the s-dimensional length of F." Which enables the use of the following expression (10) [4]:

$$M_\delta(F) \sim c\delta^{-s} \tag{10}$$

Logarithmising the previous (10) yields the following expression (11):

$$log M_\delta(F) \simeq \log c - s\, log\delta \tag{11}$$

and taking into account that δ→0, that is, that the difference between both sides is 0 with δ, s can be expressed as the following equation (12):

$$s = \lim_{\delta \to 0} \frac{log M_\delta(F)}{-log\delta} \tag{12}$$

These formulas are attractive for use for experimental or computational purposes, because the minus gradient (slope, steepness) of the logarithmic-logarithmic graph drawn within the appropriate domain of δ can be displayed (Figure 3.) [4].

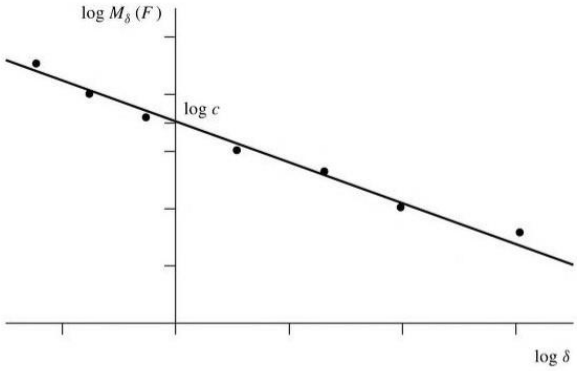

Figure 3. Logarithmic-logarithmic graph within the associated domain of δ.

Of course, this method only works with a limited domain of δ, which means that theory and experiment do not match [4], but this method allows insight into considering alternatives to the Hausdorf dimension using Falconer's claims, which allows incorporation into other more advanced methods such as the Box dimension.

1.2 Box dimension

Taking into account all the above, the final term of this paper can be introduced, which is the Box dimension [1]. In foreign literature, the term is also known as the Box-counting dimension, but also as Kolmogorov's entropy, entropy dimension, capacitive dimension (a term that is usually avoided due to possible conflicts

of associative theories), metric dimension, logarithmic dimension and information dimension. However, the term that will be used in this paper is the Box dimension [4], which is also the one most frequently used.

The main advantage of using this kind of fractal dimension is relatively easier calculation and independence from measures. At the same time, the box dimension itself is almost always greater than or equal to the Hausdorff dimension, which allows it to be used interchangeably in fractal dimension calculation methods [9].

The very definition of the Box dimension is relatively simple and requires knowledge of the upper (14) and lower bounds (13) of a function, therefore [4][9]: Let the set X be bounded by $\boldsymbol{\mathcal{R}}^n$ ($X \subset \boldsymbol{\mathcal{R}}^n$), and let there exist $N_\delta(X)$ that describes the smallest number of sets of diameter at most δ that make up the cover of the set X, that is, they can cover it for every δ>0. The lower and upper limits of the box dimensions are defined as:

$$\underline{dim}_B X = \underline{\lim_{\delta \to 0} \frac{\log N_\delta(X)}{-\log \delta}} \tag{13}$$

$$\overline{dim}_B X = \overline{\lim_{\delta \to 0} \frac{\log N_\delta(X)}{-\log \delta}} \tag{14}$$

and in cases where the lower and upper limits are equal, the common value is referred to as a box dimension of X (15):

$$dim_B X = \lim_{\delta \to 0} \frac{\log N_\delta(X)}{-\log \delta} \tag{15}$$

It must be noted that δ>0 is almost always assumed to be a sufficiently small number (the smallest possible non-negative number), so that the coefficient -logδ within the definition is always strictly positive. Also, to avoid problems that can occur when logarithmising infinity or zero, the box dimension is generally considered only for non-empty closed sets. Therefore, in the developing theory of box dimensions, including this paper, sets are considered as non-empty and closed, that is, bounded [4]. Also, since the dimension of the set X reflects the way $N_\delta(X)$ grows when δ→0, it can be concluded that if the growth of δ is faster when δ→0, the set X is more "branched" [9].

Also, if Nδ(X) satisfies the power law for positive constants c>0 and s≥0:

$$N_\delta(X) \sim c\delta^{-s}, when \ \ \delta \to 0 \tag{16}$$

and, with this, it can be concluded that the box dimension of the set X is equal to s (16) [9].

These similarities help in the definition of the box dimension itself, which will be performed, but before performing the box dimension itself, it should be clarified that the similarity between $N_\delta(X)$ and $c\delta^{-s}$ while δ→0 means that $N_\delta(X)$ asymptotically behaves like cδ^(-s), therefore the following statement [9] is valid (17):

$$\lim_{\delta \to 0} \frac{N_\delta(X)}{c\delta^{-s}} = 1 \tag{17}$$

3. A practical solution to measuring the box dimension

3.1 The programme for measuring fractal dimensions

All of the previous leads to the linchpin of this paper, which is a python program that allows for the measuring of a fractal dimension within a digital image. Simply put, the program uses Python, an interpreted, interactive, object-oriented programming language. It includes modules, exceptions, dynamic typing, very high-level dynamic data types, and classes. It supports several programming paradigms outside of object-oriented programming, such as procedural and functional programming. Python combines extraordinary power with a very clear syntax. It has interfaces for many system calls and libraries, as well as to various windowing systems, and can be extended to C or C++. It can also be used as an extension language for applications that require a programmable interface, and it is portable: it runs on many Unix variants, including Linux and macOS, as well as on Windows operating systems [10]. In other words, the Python programming language is extremely developer-friendly, and is very robust in the sense that adding modules solves the problem of older programming languages, without which developers would have to bother creating their own solutions that would not be thoroughly documented, tested, or even correct; however, the Python programming language has many modules that, each individually, represent a separate

solution for a specific problem, and this essentially means that any problem can be solved within the Python programming language. The problem of this programming language remains the fact that it is not specialized for everything, but it is capable of everything. This specific solution allows for folder wide fractal dimension measurement, meaning that users can measure a theoretically near infinite amount of fractals contained within a specific folder, barring hardware limitations.

Regarding the topic of this paper and the related task, a couple of modules have been used that enable the task to be completed relatively easily. The Python module OpenCV, which is used for displaying digital images, but also for all possible operations related to them (for example, rotation, or changing color to monochrome format), was used. This is extremely suitable for working with photographs, and essentially avoids the need to write your own program code for operations with digital images [11].

Then, for ease of use, a graphical interface for displaying photos was programmed using the PySimpleGUI module (Figure 4.). The GUI itself is used for ease of access, however the algorithms contained within serve the purpose of pre-processing the digital images in order to easily apply the box dimension measuring algorithm.

The mentioned module facilitates the programming of graphical interfaces within the Python programming language [12].

Figure 4. The first screen of the program.

In essence, the algorithms for displaying and calculating the fractal dimension are not bound within the program code itself, but when opening a specific folder, that is, the one that the user chooses to view (which should be a folder where users store pictures of fractals), the program starts an algorithm for each file that is programmed for the purpose of calculating the box dimension of the fractal from the image (Figure 5.).

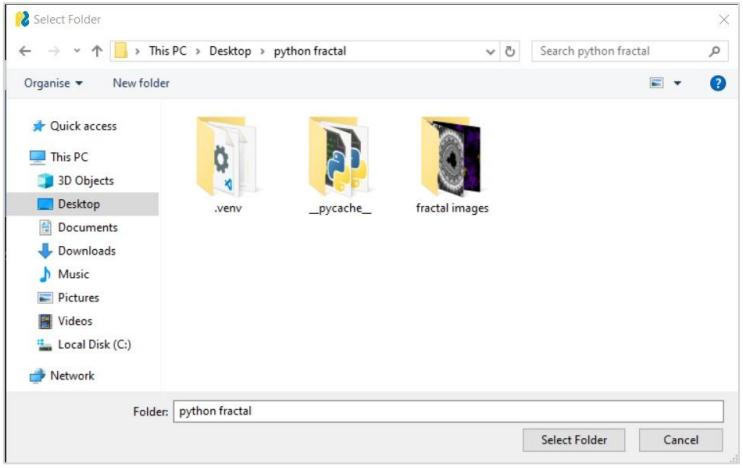

Figure 5. Opening the desired folder for displaying and calculating.

A printout of the calculated fractal dimension of a specific digital image has been added to the graphical interface, that is, the image that is marked within the interface (Figure 6.). Of course, this program follows the previously processed box dimension formula with an additional algorithm that precedes the calculation itself so that this formula can function for digital images, because computers must process data in a specific way that is not automated but programmed from case to case, essentially meaning that the formula for the box dimension had to be modified in order to work in software form.

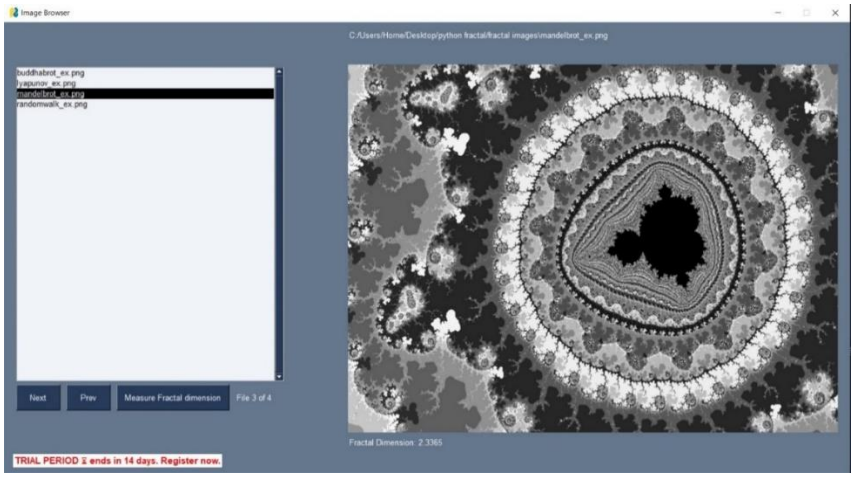

Figure 6. Fractal display and fractal dimension.

This algorithm delivers the calculated box dimension data of the image to the main graphical interface, thereby allowing users to see the box dimensions of all fractals stored within a single folder, as well as the specific box dimension values for each fractal within it. The relative speed of this process is due to the relative simplicity of the box dimension method itself, which was modified in order to be able to work as an computer program, which includes the aforementioned pre-processing algorithm for digital images and the remodelling of the box counting method to work as an algorithm that can measure the fractal dimension within an image.

This program was envisioned as a solution to two major problems within the field of fractal theory, the lack of large scale fractal sets with their fractal dimensions, as well as the distinct lack of an easy to use program to measure fractal dimensions.

4. Conclusion

Fractals are without a doubt one of the greatest discoveries of the 20th century. Their comprehensiveness revolutionizes the way geometry, and thus mathematics, is understood. The very fact that fractals were discovered and explained in the 1970s by a scientist who was not a typical mathematician of the time but, like his ancient or Renaissance predecessors, has also engaged in philosophical thought, indicates a newly established perspective that seemed unthinkable at the time; moreover, this change (of perspective) enabled the crossing of previous boundaries set in geometry, such as the description of shapes with dimensions higher than three, as well as more precise descriptions of textured surfaces that were extremely complex to explain, and thus to calculate, before the introduction of fractal theory. The program itself, developed for the purpose of practical implementation, moves a step closer to helping understand fractals and fractal dimensions, and analogously, topological dimensions, which means that this program could be used to develop similar programs that use modern technologies to improve various industries for which similar programs are already used (e.g., measuring molecular structures), as well as upgrades for existing systems. Everything that can be described in the language of mathematics can be processed in a programming language. Therefore, mathematics and programming have always been inextricably linked since the beginning of computing, and with fractals, through their role of changing structures, further strengthening this connection.

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Speech emotion detection using the equivalent torque characteristic algorithm and neural networks

Bojan Prlinčević[1], Zoran Milivojevic[2], Milan Misic[1], Dijana Kostić[3] and Violeta Stojanovic[3]

[1]Academy of Applied Studies Kosovo and Metohija, Serbia, Leposavic
[2]Department of Electrical and Computer Engineering, Engineering Academy of Serbia, Serbia, Nis
[3]Šargan inženjering" d.o.o, Niš, Serbia, Nis
[4]The Academy of Applied Technical and Preschool Studies, Serbia, Nis

E-mail: bojan.prlincevic@akademijakm.edu.rs

Abstract. This paper introduces a novel approach to speech emotion detection based on the analysis of the fundamental frequency (F0) and its derivatives, employing the concept of Equivalent Torque Characteristic (ETC). Drawing an analogy from kinematic analysis of mechanical systems, ETC is defined as the product of the first and second derivatives of the F0 trajectory. Emotional states (neutral and angry) are classified within two-dimensional planes (F0, ETC+) and (F0, ETC−), using decision-boundary algorithms including CTD, SVM, and neural networks. The experimental evaluation, conducted on the Berlin Emotional Speech Database, demonstrates that neural networks significantly outperform traditional classifiers, achieving classification accuracy up to 94.2%. The results validate the proposed ETC-based algorithm as a robust and effective solution for automatic speech emotion detection when combined with deep learning techniques.

1. Introduction

Understanding emotions expressed through speech represents a important segment of research, particularly with the increasing integration of artificial intelligence into everyday life. While humans possess the innate and intuitive ability to recognize emotions conveyed by a speaker's voice, computational systems predominantly rely on analytical methods designed to mimic this human capability. Research in the field of speech emotion recognition dates back to the 1980s and has primarily focused on the statistical analysis of acoustic features. [1].

During the 1990s, with advancements in technology, researchers began introducing more sophisticated algorithms that demonstrated improved efficiency in the analysis of emotional states [2]. Methods such as Hidden Markov Models (HMM) [3], Gaussian Mixture Models (GMM) [4], and traditional classifiers marked significant progress. Nevertheless, these techniques exhibited limitations, particularly in accurately recognizing subtle or complex emotions, especially under specific environmental conditions. A core parameter in all these analyses is the fundamental frequency (F_0), due to its strong association with the speaker's emotional state.

In recent years, speech emotion detection has undergone significant advancement, representing a transformation in the approach to emotion recognition. With the emergence and growing application of deep learning—particularly neural networks—researchers are now employing models capable of autonomously extracting speech features from large-scale datasets. These systems demonstrate remarkable generalization capabilities across different languages, cultures, and acoustic environments, effectively recognizing complex emotional expressions that often elude traditional approaches.

Contemporary advancements in this field are largely driven by the application of transformer networks, such as those examined in [5]. Additionally, lightweight ensemble models that integrate Convolutional Neural Networks (CNN) and Bidirectional Long Short-Term Memory (Bi-LSTM) frameworks have demonstrated promising results, offering an efficient yet robust solution for real-time deployment in Speech Emotion Detection systems.

The emergence of self-supervised learning methods—exemplified by the VQ-MAE-S model presented in [6]—has further enhanced the capabilities of emotion recognition systems by reducing dependence on large labeled datasets. Moreover, hybrid architectures that combine CNNs [7] with transformer blocks and

enhanced attention mechanisms, as analyzed in [8], have substantially improved the system's ability to simultaneously process both temporal and spectral characteristics of speech.

These innovations indicate a clear trajectory toward the development of more intelligent and adaptive detection mechanisms, thereby enabling their practical implementation in domains such as virtual assistants, mental health assessment, and human–computer interaction.

Pattern classification represents a key application of Artificial Neural Networks (ANN). In the domain of Digital Signal Processing (DSP), classification techniques are utilized in a wide range of tasks, including speech recognition, speaker emotional state detection [9][10], handwritten text and character recognition, facial recognition, fingerprint identification, target identification via radar/sonar, biomedical signal diagnosis, and numerous other applications [11].

In papers [12] and [13], algorithms for positioning in the planes (F_0, σ), (F_0, T), (F_0, $F_0'_+$) i (F_0, $F_0'_-$) were presented. In this paper, the authors propose a novel algorithm for emotional state recognition from the speech, based on the trajectory analysis of the speech fundamental frequency (F_0). The concept for this algorithm was inspired by the kinematic analysis of cam mechanisms [14], where standardized transfer functions C_υ - velocity characteristic, Ca - Acceleration characteristic, C_J - jerk characteristic, $C_{\text{m_stat}}$ – Static Torque characteristic, $C_{\text{M_dyn}}$ - dynamic torque characteristic are derived from kinematic quantities (trajectory, velocity, acceleration) for the purpose of optimizing camshaft load under inertial forces.

An analogy was established between the dynamic torque characteristic and the fundamental frequency trajectory by mapping kinematic quantities to acoustic parameters: trajectory <-> F_0(t), velocity <-> F_0'(t), and acceleration <-> F_0''(t). The Equivalent Torque Characteristic (ETC) was defined as the product of velocity and acceleration. For each emotional speech signal, the ETC is computed and the emotional state is mapped in the (F_0, ETC) plane. The separation and classification between emotional states—specifically "neutral" and "anger"—was performed using classification algorithms: (a) CTD, (b) VSM, and (c) artificial neural networks.

An experiment was performed employing two algorithms—one for training and one for testing the classifiers. These algorithms were applied to a database of emotional speech signals generated at Technische Universität Berlin [15]. Decision boundaries were graphically presented. The performance of emotional state detection was evaluated using parameters derived from the confusion matrix: , N, TP, FP, TN, FN, PPV = TP/(TP + FP), NPN = TN / (TN + FN), ACC = (TP + TN)/(P + N), TPR = TP / P, FPR = FP / N, FNR = FN / P and TNR = TN / N. Finally, a comparative analysis was conducted using the accuracy (ACC) metric.

2.– Equivalent Torque Characteristic ETC algoritam

In [14], the selection of standardized transfer functions was analyzed with the aim of defining operational conditions for the cam mechanism. The following functions were examined: (a) Velocity characteristic, $C_v = max\, f'(z) = f'(0.5)$, which should be minimized to reduce the amount of kinetic energy stored in the inertial mass, thereby decreasing the required drive torque for the cam mechanism; (b) Acceleration characteristic, $C_a = max\, f''(z) = f''(z_a)$; (c) Jerk characteristic $C_j = max\, f'''(z) = f'''(z_j)$, (d) Static Torque characteristic $C_{M_stat} = C_v = max\, f'(z) = f'(0.5)$, and (e) Dynamic Torque characteristic $C_{M_dyn} = C_M = max[f'(z) \cdot f''(z)] = f'(0.5)$.

An analogy was established with the Dynamic Torque Characteristic, leading to the formulation of the Equivalent Torque Characteristic (ETC). A general analogy was defined between kinematic quantities (trajectory, velocity, and acceleration) and the trajectory of the fundamental frequency in speech signals (F_0, F_0', F_0''). Figure 1 illustrates the following: (a) the F_0 trajectory, (b) its first derivative, (c) its second derivative, and (d) the product of the first and second derivatives of the fundamental frequency. For the purposes of further analysis, two ETC formulations were created:

$$ETC_+ = \frac{1}{N}\sum_{n=0}^{N-1} F_0^{(1)}(n) \cdot F_0^{(2)}(n), \text{ for } F_0^{(1)}(n) \cdot F_0^{(2)}(n) \geq 0, \quad (***)$$

$$ETC_- = \frac{1}{N}\sum_{n=0}^{N-1} F_0^{(1)}(n) \cdot F_0^{(2)}(n), \text{ for } F_0^{(1)}(n) \cdot F_0^{(2)}(n) \leq 0, \quad (****)$$

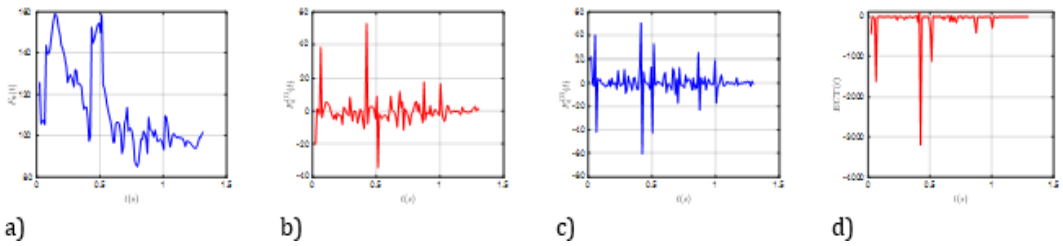

Figure 1. Fundamental frequency F_0: (a) trajectory, (b) first derivative, (c) second derivative, and (d) product of the first and second derivatives.

3. Experimental Results and Analysis

An experiment was conducted in which the ETC algorithm was used for emotion detection within the (F_0, ETC) plane. To compute the decision boundary—that is, to define the boundary in the plane between emotional states—the following algorithms were employed: (a) CTD, (b) VSM, and (c) artificial neural network.

The experiment was carried out in two phases: (a) Training phase (Algorithm 1) – during which the classifiers were trained and the decision boundary was created, and (b) Testing phase (Algorithm 2) – in which the trained models were applied to test speech signals.

The Algorithm 1 and Algorithm 2 are performed according to the following steps:

Algorithm 1 – Training

Input: x_K – audio signal, $k = 1, 2, \ldots, K$, where K - total number of speech signals

Output: NN_1, NN_2 - Neural networks; CP_+, CP_- - Statistical parameters derived from the confusion matrix

FOR $k = 1 : K$

Step 1: Generation of the fundamental frequency trajectory $F_{0,k}(t)$ using FFT (Praat);

Step 2: Determination of the mean value of the fundamental frequency trajectory $F_{m,k} = \overline{F_{0,k}(t)}$;

Step 3: Calculation of the first derivative of the fundamental frequency trajectory $F_{0,k}^{(1)}(t)$;

Step 4: Calculation of the second derivative of the fundamental frequency trajectory, i.e. $F_{0,k}^{(2)}(t)$;

Step 5: Construction of the Equivalent Torque Characteristic ETC, $ETC_{0,k}(t) = F_{0,k}^{(1)}(t) \cdot F_{0,k}^{(2)}(t)$

Step 6: Calculation of the mean value for $ETC_{k,+} = \overline{ETC_k(t)}$ for $ETC_k > 0$

Step 7: Calculation of the mean value for $ETC_{k,-} = \overline{ETC_k(t)}$ for $ETC_k < 0$

END k

Step 8: Construction of the plane (F_0, ETC_+) and distribution of points ($F_{m,k}$, $ETC_{k,+}$), followed by training of the algorithms and neural network NN_1.

Step 9: Computation of statistical parameters of the confusion matrix (CP_+)

Step 10: Construction of the plane (F_0, ETC_-) and distribution of points ($F_{m,k}$, $ETC_{k,-}$), followed by training of the algorithms and neural network NN_2.

Step 11: Computation of statistical parameters of the confusion matrix (CP_-)

Algorithm 2 – testing

Input: x_K – audio signal, $k = 1, 2, \ldots, K$, where K - is the total number of speech signals, NN_1, NN_2 – pre-trained neural networks.

Output: CP_{NN2}, CP_{NN2} - statistical parameters derived from the confusion matrix, corresponding to the performance of the applied algorithms and neural networks.

FOR $k = 1 : K$

Step 1: Creating of the fundamental frequency trajectory $F_{0,k}(t)$ using FFT (Praat);

Step 2: Determination of the mean value of the fundamental frequency trajectory $F_{m,k} = \overline{F_{0,k}(t)}$;

Step 3: Calculation of the first derivative of the $F_{0,k}^{(1)}(t)$ trajectory;

Step 4: Calculation of the second derivative of the F_0 trajectory $F_{0,k}^{(2)}(t)$;

Step 5: Construction of the Equivalent Torque Characteristic (ETC), $ETC_{0,k}(t) = F_{0,k}^{(1)}(t) \cdot F_{0,k}^{(2)}(t)$;

Step 6: Calculation of the mean value for $ETC_{k,+} = \overline{ETC_k(t)}$ for $ETC_k > 0$;

Step 7: Calculation of the mean value for $ETC_k < 0$ $ETC_{k} < 0$ $ETC_{k,-} = \overline{ETC_k(t)}$ for $ETC_k < 0$;

END k

Step 8: Construction of the (F_0, ETC_+) plane and distribution of points ($F_{m,k}$, $ETC_{k,+}$);

Step 9: Emotion classification using the algorithms and neural network NN_1 (statistical parameters - CP_{NN1})

Step 10: Construction of the (F_0, ETC_-) plane and distribution of points ($F_{m,k}$, $ETC_{k,-}$);

Step 11: Emotion classification using neural network NN_2 (statistical parameters: CP_{NN2})

In the experiment, a specialized version of a feedforward neural network designed for pattern recognition was created and trained. The neural network was implemented in MATLAB using the patternnet function. The architecture employed the default tangent-sigmoid (tansig) transfer function in both the hidden and output layers. The selected network structure included two hidden layers with sizes [4, 2]. The training process used the default scaled conjugate gradient backpropagation algorithm (trainscg). The network input consisted of a feature vector $[F_{0m}, ETC]^T$. Through supervised learning, the network mapped the input feature space to a two-class output space, represented as [*Emotion1*, *Emotion2*]^T. For an input vector belonging to a given category, the corresponding neuron in the output layer—representing that emotion class—was expected to output a 1, while the other neuron would output a 0.

The algorithms were applied to test signals from a purpose-built emotional speech database. As a result of training and testing, evaluation parameters were generated based on confusion matrices (Confusion Parameters – CP).

3.1 Speech Signal Database

The recording setup included a Sennheiser MKH 40 P 48 microphone and a Tascam DA-P1 portable DAT recorder. In addition to the pure audio data, electroglottograms were captured using a portable laryngograph (Laryngograph Ltd.). Recordings were made at a sampling frequency of 48 kHz and subsequently downsampled to 16 kHz [16].

Recordings were taken with a sampling frequency of 48 kHz and later downsampled to 16 kHz [16]. In this paper, two emotional states—neutral and anger—were selected for analysis. Representative utterances for each state were chosen, and the analysis includes both the speech signal and the fundamental frequency contour (F_0(t)) for a male and a female speaker pronouncing the sentence: *"Sie haben es gerade hochgetragen und jetzt gehen sie wieder runter"* (Translation on englih: *"They just carried it upstairs, and now they are coming down again."*)

3.2 Results

Using the ETC algorithm, the locations of points with coordinates (F_{0i}, ETC_i) in the plane were determined for training speech signals: (a) (F_0,ETC_+) — Figure 2 and (b) (F_0,ETC_-) — Figure 4. Similarly, the ETC algorithm was used to map the positions of points corresponding to testing speech signals: (a) F_0,ETC_+ — Figure 3 and (b) (F_0,ETC_-) — Figure 5. The decision boundaries were computed using: (a) CTD (Figure 2.a, Figure 4.a), (b) SVM (Figure 2.b, Figure 4.b), and (c) neural network (Figure 2.c, Figure 4.c). Confusion matrix parameters for both training and testing using CTD, SVM, and neural network classifiers are presented in: (a) Table 1 for (ETC_+) and (b) Table 2 for (ETC_-).

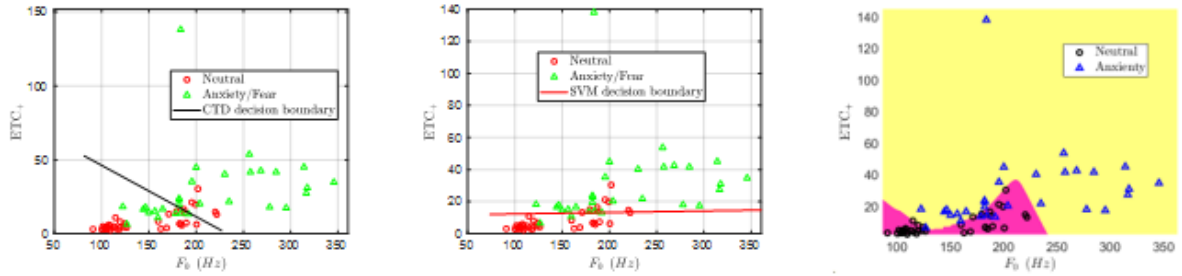

Figure 2. Decision boundary in the (F_0,ETC+) plane:(a) CTD algorithm, (b) SVM algorithm, and (c) neural network NN1.

Table 1. Confusion matrix parameters for the (F_0,ETC$_+$) plane for training and testing

	Training			Testing		
	CTD	SVM	NN	CTD	SVM	NN
P	30	30	30	22	22	22
N	39	39	39	18	18	18
TP	19	2	26	14	7	18
FP	6	31	0	2	17	1
TN	33	8	39	16	1	17
FN	11	28	4	8	15	4
PPV	0.7600	0.0606	1	0.6364	0.3182	0.9474
NPV	0.7500	0.2222	0.9070	0.8889	0.0556	0.8095
ACC	0.7536	0.1449	0.9420	0.7500	0.2000	0.8750
TPR	0.6333	0.0667	0.8667	0.6364	0.3182	0.8182
FPR	0.1538	0.7949	0	0.1111	0.9444	0.0556
FNR	0.3667	0.9333	0.1333	0.3636	0.6818	0.1818
TNR	0.8462	0.2051	1	0.8889	0.0556	0.9444

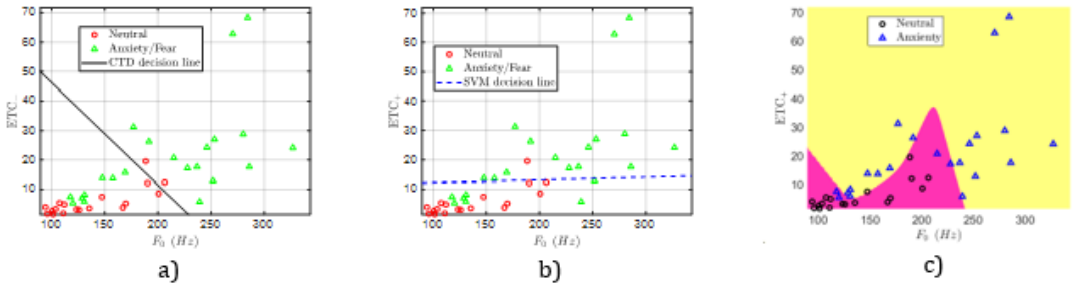

Figure 3. Testing in the (F_0,ETC$_+$) plane: (a) CTD algorithm, (b) SVM algorithm, and (c) neural network NN1.

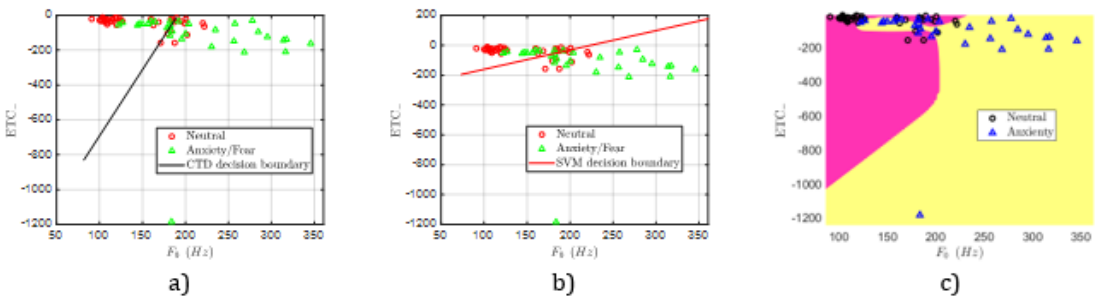

Figure 4. Decision boundary in the (F_0,ETC-) plane:(a) CTD algorithm,(b) SVM algorithm, and (c) neural network NN2.

Table 2. Confusion matrix parameters for the (F_0,ETC-) plane during training and testing

	Training			**Testing**		
	CTD	SVM	NN	CTD	SVM	NN
P	30	30	30	22	22	22
N	39	39	39	18	18	18
TP	19	20	25	13	14	18
FP	12	8	5	4	3	1
TN	27	31	34	14	15	17
FN	11	10	5	9	8	4
PPV	0.6129	0.7143	0.8333	0.5909	0.6364	0.9474
NPV	0.7105	0.7561	0.8718	0.7778	0.8333	0.8095
ACC	0.6667	0.7391	0.8551	0.6750	0.7250	0.8750
TPR	0.6333	0.6667	0.8333	0.5909	0.6364	0.8182
FPR	0.3077	0.2051	0.1282	0.2222	0.1667	0.0556
FNR	0.3667	0.3333	0.1667	0.4091	0.3636	0.1818
TNR	0.6923	0.7949	0.8718	0.7778	0.8333	0.9444

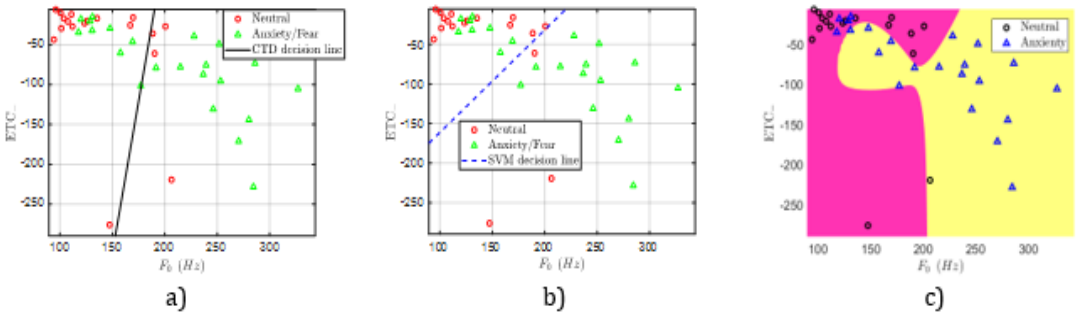

Figure 5. Testing in the (F_0,ETC-) plane: (a) CTD algorithm, (b) SVM algorithm, and (c) neural network NN2.

3.3 Comparative Analysis of Results

The Accuracy (ACC) metric was used as the criterion for comparison. In the analysis within the ((F_0, ETC+) plane, the best results were achieved using the neural network NN1, as follows:

a) Training phase: ACC_{NN1} = 0.9420 (table 1). Compared to CTD, the neural network yielded a 1.25-fold improvement in accuracy ACC_{NN1} / ACC_{CTD} = 0.942 / 0.7536 = 1.25; Compared to SVM, the improvement was 6.501,- ACC_{NN1} / ACC_{SVM} = 0.9420 / 0.1449 = 6.501

b) Testing phase: ACC_{NN1} = 0.8750. The improvement relative to CTD was 1.1666- ACC_{NN1} / ACC_{CTD} = 0.8750 / 0.750 = 1.1666, and compared to SVM: ACC_{NN1} / ACC_{SVM} = 0.8750 / 0.2 = 4.375.

In the analysis of the (F_0, ETC-) plane, the highest results were obtained using neural network NN2:

a) Training phase**:** ACC_{NN2} = 0.8551 (table 2). Compared to CTD: 0.8551 / 0.6667 = 1.2825, Compared to SVM: 0.8551 / 0.7391=1.157.

b) Testing phase: ACC_{NN2} = 0.8750. Compared to CTD: 0.8750 / 0.6750=1.2962 \; Compared to SVM: 0.8750 / 0.7250=1.2068.

Additionally, training in the (F_0, ETC-) plane resulted in higher performance than training in the (F_0, ETC-) plane, with a relative improvement: ACC_{NN1} / ACC_{NN2} = 0.9420 / 0.8551 = 1.1016.

These results and the comparative analysis clearly indicate that emotion recognition in the (F_0, ETC+) plane using a neural network provides the optimal solution.

In a previous paper [12], emotion classification in the (F_0, F_0') plane using a linear decision boundary and CTD algorithm achieved an accuracy (ACC) of **75%** for the positive derivative component (P(F_0, $F_0'_+$)), while the accuracy for the negative derivative component (P(F_0, $F_0'_-$)) was significantly lower at **27.5%**. Precision was **83.3%** for $F_0'_+$, and **37.9%** for $F_0'_-$, while recall reached **68.2%** and **50%**, respectively. These

findings suggest that applying only the first derivative of F_0 with linear boundaries has limited effectiveness for emotional state recognition.

In paper [13], an enhanced method was proposed by incorporating additional metaparameters; however, classification remained based on traditional algorithms without the use of neural networks. The achieved performance remained within the bounds of previous results, further underscoring the limitations of conventional methods in complex emotional expression analysis.

In contrast, the present paper introduces the Equivalent Torque Characteristic (ETC) approach—combining the first and second derivatives of F_0'- —and applies neural networks, resulting in the highest reported accuracies to date:

- Training ACC = 94.2% in the (F_0, ETC_+) plane
- Testing ACC = 87.5%

Compared to [12], which achieved a maximum accuracy of 75%, the new algorithm offers an improvement exceeding 25%. Relative to the SVM algorithm from the same study (ACC = 14.5%), the proposed neural network approach achieves over six times higher precision.

These results provide clear evidence of the superiority of the ETC-based approach and deep learning techniques over linear-separator-based methods in speech emotion recognition.

4. Conclusion

This paper presented an original method for Speech Emotion Recognition (SER) based on an analogy between the kinematic characteristics of mechanical systems and the dynamics of acoustic speech signals. By introducing the Equivalent Torque Characteristic (ETC), computed as the product of the first and second derivatives of the fundamental frequency (F_0), emotional states were effectively represented within two-dimensional planes (F_0, ETC_+) and (F_0, ETC_-).

Through the application of CTD, SVM, and neural network classifiers, the experimental results demonstrated that neural networks significantly outperformed traditional methods, achieving a maximum classification accuracy of 94.2%.

These findings confirm that ETC-based features, when combined with neural networks, provide a robust and efficient solution for automatic SER, with promising applications in human–computer interaction, virtual assistants, and emotional state monitoring systems.

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Open RAN performance evaluation in 6G Networks

Stojan Kitanov[1] and Ivan Petrov[2]

[1]Mother Teresa University, Faculty of Information Sciences, Republic of North Macedonia, Skopje
[2]University American College Skopje, School of Computer Science and Information Technology, Republic of North Macedonia, Skopje

E-mail: stojan.kitanov@unt.edu.mk

Abstract. The transition to 6G networks requires a more open, adaptable, and intelligent RAN architecture. The Open Radio Access Network (O-RAN) provides vendor-neutral, disaggregated RAN components and AI-driven control, making it a strong candidate for future networks. This paper assesses O-RAN's performance in a 6G mobile networks in terms of latency and network throughput.

1. Introduction

6G (Sixth Generation) mobile networks are the next generation of wireless communication systems after 5G, with an estimated debut date of 2030 [1]. They want to address the growing demand for ultra-fast, ultra-reliable, intelligent, and long-lasting connectivity in future digital ecosystems including the metaverse, digital twins, holographic communications, and ubiquitous Artificial Intelligence (AI) [2].

The 6G ecosystem emphasizes ultra-low latency, high throughput, and massive device connectivity. Traditional RANs fall short of providing the flexibility required for such goals.

Open RAN (O-RAN) is the disaggregation of radio access network (RAN) components developed using open interface specifications across elements, such as open fronthaul, and enabled by software virtualization [3]. This technique allows for implementation on vendor-independent hardware and software-defined technology, with open interfaces and jointly established standards. Furthermore, Open RAN incorporates intelligence from AI/ML open platforms to increase network efficiency and user experience.

Moving to an open and intelligent virtual RAN (vRAN) based on O-RAN standards enables them to establish an innovative RAN environment that incorporates cloud economics, which is a critical component for delivering services over the 5G network. The ultimate goal is to give real-time radio resource management capabilities via platform applications.

The Open RAN principles include (i) a disaggregated architecture with modular and standardized interfaces; (ii) cloudification, programmability, and orchestration; and (iii) AI-enabled data-centric closed-loop control and automation.

In the context of 6G networks, Open RAN plays a critical role in achieving flexibility, scalability, energy efficiency, and AI-native operations [4]. This paper assesses O-RAN's performance in a 6G setting using key parameters like latency, spectrum efficiency, energy consumption, and throughput. It presents a MATLAB simulation framework for evaluating the effects of disaggregation and RAN Intelligent Controller (RIC) interventions on system performance.

The rest of the paper is structured as follows. Section 2 provides an overview of 6G networks. Section 3 focuses on Open RAN. Section 4 proposed a 6G O-RAN Architecture. Section 5 performs evaluation of the architecture in terms of network throughput and latency. Finally, Section 6 concludes the paper and proposes directions for future work.

2. Overview of 6G Mobile Network

The sixth-generation wireless network, or 6G, marks the next step in mobile communications after 5G. 6G mobile and wireless networks would provide large coverage, allowing customers to interact with one another anywhere at a high data rate speed. While 6G is still in its early stages of development and research (standardization and

implementation are expected around 2030), it is poised to transform connection with unparalleled speed, low latency, and advanced capabilities.

Below are outlined some of the main 6G key features [5]:

- Ultra-High Speeds - anticipated data rates of up to 1 Tbps (terabits per second), far exceeding the maximum speeds of 5G, and enhanced capabilities for applications requiring massive bandwidth.
- Ultra-Low Latency - expected latency below 1 millisecond, enabling real-time applications like immersive VR/AR, autonomous vehicles, and remote surgeries.
- Terahertz (THz) Frequencies - utilization of sub-terahertz and terahertz frequencies (0.1–10 THz) for significantly higher data rates and spectral efficiency.
- AI Integration - built-in artificial intelligence and machine learning for network optimization, predictive maintenance, and automated decision-making.
- Holographic Communication - support for real-time holographic displays, enabling lifelike interactions for communication, education, and entertainment.
- Massive IoT and Sensing - seamless integration of trillions of IoT devices, where 6G networks will also function as advanced sensors, supporting environmental monitoring, health tracking, and industrial automation.
- Enhanced Security and Privacy - Quantum computing-based encryption and advanced cybersecurity protocols to safeguard data.

6G networks would enable several new use cases that 5G cannot fully cover [6]. Some of the 6G potential use cases and applications include the following:

- Smart Cities: Fully autonomous systems for traffic management, energy distribution, and public safety.
- Healthcare: Remote surgeries with robotic precision and advanced diagnostics using wearable sensors.
- Immersive Technologies: Enhanced virtual reality, augmented reality, and mixed reality experiences.
- Space Communication: Interconnected networks supporting satellite communication and space exploration.
- Sustainable Technologies: Energy-efficient networks using renewable energy sources.

The most prominent and recently proposed enabling technology for the 6G network is artificial intelligence (AI) [7]. AI would be the driving force behind building and optimizing 6G architectures, protocols, and operations. 6G networks combined with AI would enable ubiquitous and mobiquitous smart services from the network's core to its end devices, exceeding current mobile data traffic. AI is projected to drive the wireless transition from "connected things" to "connected intelligence" [1].

6G networks would adopt ubiquitous AI solutions from the network core to the edge devices. AI would be implemented at any horizontal or vertical level, at all TCP/IP levels, slice configurations, and cloud-based network resources (edge computing). The end result would be a self-sustaining, ultra-smart network capable of providing advanced self-managed services.

The design of a 6G network would include descriptive, diagnostic, predictive, and prescriptive AI data analytics [7–8]. The network analytics proposed in this design would evaluate collected historical data to provide insights into the network status, particularly at the PHY, MAC, Network, and Transport layers. Core data analytics will use the data generated by network analytics operations to discover and anticipate network anomalies in order to improve network reliability and security. The acquired data would be utilized to detect future issues using history and present information, as well as network activity.

This procedure should produce resource allocation solutions and notifications as its output. Predictive analytics uses data to forecast future resource availability based on user mobility, traffic trends, and overload. It is envisaged that efficient solutions for resource allocation, network virtualization and slicing, edge computing, and optimization of virtual network devices will be proposed in order to provide maximum network utilization, data transfer speed, and traffic QoS. In some cases, core and predictive analytics may overlap. Even if this situation appears to be simplistic, it is not; it must take into account a

large number of parameters, such as big data deep learning processes, which must be improved if end-to-end traffic optimization is employed.

Edge Intelligence (EI) or edge AI, which is placed at the network's edge, is another promising computing paradigm that is gaining traction [9]. Big data sources as an enabling technology for learning-based solutions have recently seen a considerable movement away from cloud data centers and toward ever-increasing edge devices such as smartphones and industrial IoT. These edge devices would undoubtedly drive AI solutions to the network's edge, allowing them to fully leverage the potential of edge large data sources.

3. Overview of Open RAN (ORAN)

The mobile or cellular/wireless network is divided into two domains: the Radio Access Network (RAN) and the Core Network [10].

The Core Network has numerous functions. It provides access controls to ensure that users are verified for the services they use, routes phone calls over the public switched telephone network, allows operators to charge for calls and data usage, and connects users to the rest of the world via the Internet. It also manages the network by triggering handovers when a user travels from one RAN tower's coverage to another.

The RAN is the final connection between the network and the phone. It is the visible component, which comprises the antennae seen on skyscrapers, buildings, and stadiums, as well as the base stations. When a user calls or connects to a remote server, such as to watch a YouTube video, the antenna sends and receives signals to and from user's smartphone or other handheld device. The signal is subsequently digitalized at the RAN base station and routed to the network.

Table 1. A Comparison between Traditional RAN and Open RAN.

Feature	Traditional RAN	Open RAN
Vendor Dependancy	Proprietary solutions from single vendors	Multi-vendor interoperability
Interfaces	Closed and proprietary	Open and standardized
Hardware - Software	Integrated monolithic systems	Disaggregated: Software runs on COTS hardware
Innovation pace	Slow, vendor driven	Fast, community driven (open innovation)
Cost	Higher (CAPEX/OPEX)	Reduced cost via competition and reuse

Open RAN (Open Radio Access Network) is a new approach to mobile network development that prioritizes openness, interoperability, and flexibility, marking a substantial departure from the traditional, vendor-locked systems utilized in 4G and early 5G deployments. Open RAN, or Open Radio Access Network, is a shift in how mobile networks are built, promoting flexibility, interoperability, and innovation by using non-proprietary components from various vendors [3].

The goal of O-RAN is to change the radio access network industry from vendor lock to open, intelligent, virtualized, and fully interoperable RAN with open interoperable interfaces based on RAN visualization and AI-enabled RAN intelligence.

A comparison between the Open RAN and the traditional RAN is provided in Table 1. The main benefits of Open RAN over the traditional RAN are the following:

- Vendor Diversity: Reduces dependency on a single vendor.
- Lower Costs: Uses commercial off-the-shelf (COTS) hardware.
- Faster Innovation: Open interfaces encourage rapid feature development.
- AI and Automation: Enables intelligent RAN optimization via RIC.

4. Open RAN in 6G Mobile Network

Within 6G networks, OpenRAN is pivotal in enabling a flexible and scalable radio access infrastructure that supports energy-efficient communication and native integration of artificial intelligence for dynamic network optimization [4]. The deployent of Open RAN in 6G networks is expected to:

- Embed AI natively in RICs for autonomous RAN control.
- Leverage edge intelligence for low-latency decisions.
- Support holographic, tactile, and XR use cases via agile and intelligent infrastructure.
- Enable "Zero-touch" networks with full automation and predictive maintenance.

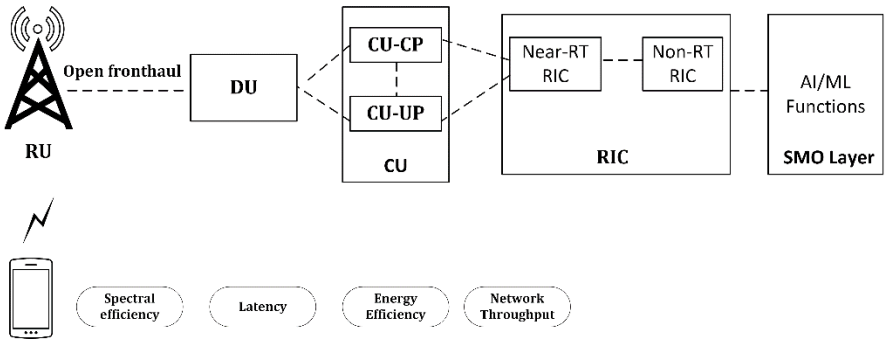

Figure 1. Open RAN Architecture in 6G Mobile Networks.

The Open RAN architecture in 6G is presented in Figure 1. The architecture contains modular design and AI-driven control loop, which would enable flexible deployment of 6G, as well as, performance optimization in 6G network. It consists of the following components: Radio Unit (RU), Distributed Unit (DU), Central Unit (CU), RAN Intelligent Controller (RIC), and Service Management Orchestration (SMO) Layer.

The Radio Unit handles radio frequency (RF) transmission and reception with user devices (e.g., smartphones). Usually, it is deployed at the cell site (antenna towers). It connects to the DU via the Open Fronthaul, which could use Enhanced Common Public Radio Interface (eCPRI) or ORAN-defined interfaces, that enables interoperability between different vendors' equipment

The Distributed Unit handles MAC, RLC, and PHY layers, and it is responsible for real-time lower-layer processing, such as scheduling, and HARQ. It connects upward to the Central Unit, and it communicates with the RIC for dynamic control.

The Central Unit is divided into CU-CP (Control Plane) that handles signaling, RRC, and mobility and CU-UP (User Plane) which manages data plane functions. By separating the control plane and user plane functions, independent scaling of signaling and user data is enabled and much more efficient resource utilization and better network performance is provided. The CU-CP and CU-UP communicate internally and both interact with the Near-RT RIC, which manages the logical separation and coordination of control/user planes

RAN Intelligent Controller is responsible for managing and optimizing RAN functions in real-time using artificial intelligence and machine learning. Primarily it has an impact on energy efficiency through power control, latency reduction via dynamic schedulling and throughput via intelligent beamforming. It consists of Near-Real-Time RIC and Non-Real-Time RIC.

Near-RT RIC (Near-Real-Time RIC) executes near-real-time (under 10 ms) control and optimization tasks, such as dynamic resource allocation, interference management, and mobility management. Non-RT RIC (Non-Real-Time RIC) on the other side handles non-real-time functions (beyond 1 second), like long-term planning, policy management, and training machine learning models.

The Service Management and Orchestration (SMO) layer contains AI/ML functions which are responsible for training and updating AI/ML models used for network optimization. It Communicates with the Non-RT RIC. In 6G, with native AI/ML and complex multi-domain orchestration, the interface between SMO and Non-RT RIT will be crucial to distribute AI knowledge across domains (cloud to edge), for adapting slicing policies for URLLC, eMBB, and mMTC, and to reduce signaling overhead via smarter policies.

5. Performance Evaluation of Open RAN in 6G Mobile Network

According to the diagram in Figure 1, the performance evaluation of Open RAN in 6G networks for each data block can be performed in the following performance metrics:

- Spectral Efficiency: How effectively bandwidth is used.
- Latency: Total time from data generation to reception.
- Energy Efficiency: Data delivered per unit of energy.
- Network Throughput: Overall data transfer capacity (bps).

The main focus in this section is the performance evaluation of Open RAN in 6G networks in terms of latency as a function of DU-CU separation (transport delay) and network throughput based on Shannon capacity. Simulation parameters are provided in Table 2.

According to Shannon Capacity the network throughput is:

$$T = B \cdot \log_2(1 + SINR) \quad (1)$$

where T is the throughput (bps), B is the channel bandwidth (Hz), and $SINR$ is Signal-to-Interference-plus-Noise-Ratio.

Table 2. Simulation Parameters.

Parameter	Value
Bandwidth (B)	100 MHz
Transmit Power (Pt)	1 W
Noise Power Spectral Density	10^{-9} W/Hz
Interference	0.01 W
Channel Gain	10
SNR	0 to 30 dB
Propagation Speed	2×10^8 m/s
DU processing delay	0.1 ms
CU processing delay	0.2 ms
RIC control delay	0.2 ms

DU – CU distance	0 to 50 km

The total end-to-end latency is calculated as a sum of transport delay, DU processing delay, CU processing delay and RIC control delay, where transport delay is calculated as:

$$TD = \frac{d}{v} \tag{2}$$

where *TD* is the transport delay, *d* is the CU-DU distance, and *v* is the propagation speed in the optical fiber between CU and DU.

The network throughput is shown on Figure 2. Throughput simulates channel capacity across a range of SINR values, and reflects effects of interference, noise, and channel conditions in Open RAN. It can be noticed that the throughput increases as SINR increases.

The latency is shown on Figure 3. Latency on the other hand models total end-to-end latency (DU + CU + RIC + transport) and it shows the impact of physical separation in a disaggregated RAN. It can be noticed that latency increases linearly with distance due to fiber transport delay. The RU, DU, and CU are often placed in different physical locations (e.g., DU at the edge site, CU in a regional data center). The further apart they are, the more latency is introduced over the fronthaul/midhaul network. According to 6G targets the latency should be less than 0.1 ms, so even tens of kilometers of DU–CU separation can consume a large portion of the latency budget. Reducing latency to meet 6G requirements (targeting less than 0.1 ms end-to-end delay) is extremely challenging and requires a multi-layered, cross-domain approach across physical, network, and control layers.

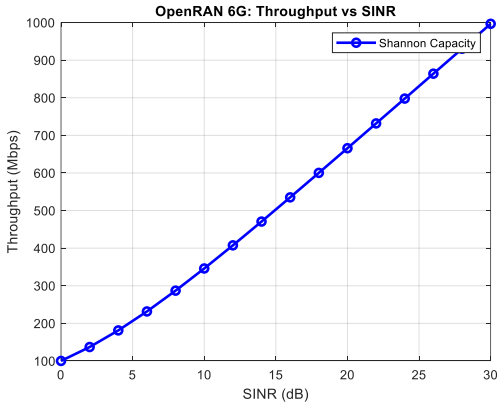

Figure 2. Throughput versus SINR in 6G Open RAN.

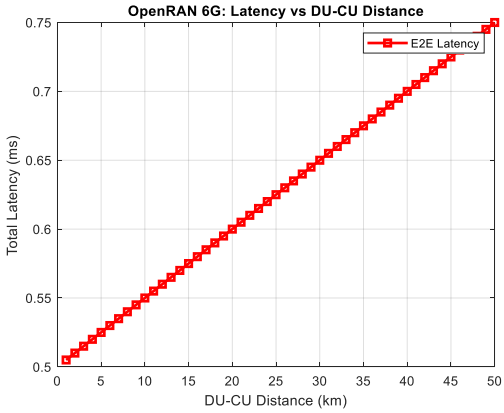

Figure 3. Latency versus DU-CU Distance in 6G Open RAN.

3. Conclusion

OpenRAN greatly improves flexibility and performance in 6G, particularly when combined with AI-based RICs. The throughput increases as SINR is increases. However, different various throughput models for 6G network should be considered. In addition, obtaining ultra-low latency and synchronization across distributed units is still a difficulty. Future research should also focus on real-time AI deployment and hardware-accelerated RAN components. In addition spectral efficiency and energy efficiency for OPEN RAN deployment in 6G network should also be considered.

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Measurement and Performance Analysis of LoRa Communication in a Real-World Environment

Azra Toroman, Enis Džanić and Admir Midžić

University of Bihać, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina

E-mail: azra.toroman@unbi.ba

Abstract LoRa is a communication technology known for its long range and low power consumption, making it suitable for a wide range of IoT applications. Although it is most often used in conjunction with the LoRaWAN protocol, which features a centralized network architecture with gateways and servers, there are scenarios where direct communication between nodes without LoRaWAN is more suitable. This paper analyzes the performance of a LoRa system in a simple configuration with three nodes (Heltec LoRa 32) communicating directly, without multi-hop communication. The focus of the research is on measuring key communication parameters — signal-to-noise ratio (SNR) and received signal strength indication (RSSI) — at different distances. The measurements were performed under real-world conditions, in both urban and rural environments, to evaluate the reliability of the LoRa connection in simple single-hop scenarios and assess its potential for practical IoT applications. Based on the tests conducted, it was determined that the effective range of LoRa connections in urban environments is reduced by more than 30% compared to rural environments, indicating a significant impact of urban obstacles on the quality of communication.

1. Introduction

LoRa (Long Range) is a wireless radio frequency technology that enables long-distance, low-power communication between devices. As the name implies, its primary advantage is long-range connectivity, allowing wireless links that extend significantly farther than those offered by technologies such as WiFi or Bluetooth. LoRa represents a physical layer or wireless modulation method used to establish long-range communication links, based on chirp spread spectrum (CSS) modulation.

LoRa is not a communication protocol but a modulation technique—a method for encoding data onto radio waves to enable efficient communication between devices. When combined with the LoRaWAN protocol, it can form a complete long-range communication network for Internet of Things (IoT) devices. Most wireless technologies follow a trade-off: greater range requires greater power consumption. However, LoRa breaks this pattern. Compared to traditional amplitude-shift keying (ASK) and frequency-shift keying (FSK) modulation, LoRa's CSS modulation significantly increases communication range, enabling transmission over several kilometers while maintaining exceptionally low energy consumption.

A key consideration when implementing LoRa technology in real-world IoT networks is: what are the actual communication ranges and the quality of the connection under varying environmental conditions? While manufacturers often cite theoretical ranges of several kilometers, practical performance varies depending on factors such as object density, the presence of obstacles, terrain type, and electromagnetic interference [1].

Previous studies have highlighted substantial differences in the quality and range of LoRa communication, depending on the surrounding environment. In [2], the authors emphasize that Low Power Wide Area Network (LPWAN) technologies, including LoRa, offer low power consumption and long range, but are sensitive to environmental conditions. The study in [3] analyzed the performance of a LoRa network for water leakage detection in a residential complex, observing fluctuations in RSSI and SNR values depending on location and surroundings. Research in [4] demonstrates that RSSI values in urban and indoor environments significantly differ from those recorded in open areas, with reliable communication typically occurring at RSSI values better than –110 dBm. Moreover, the authors in [5] compared the

performance of LoRaWAN networks in various scenarios and concluded that the spatial distribution of nodes is critical for connection reliability, particularly in complex urban environments.

The performance of LoRa communication can vary greatly between urban and rural settings. In urban areas, signals face reflections, absorption, and multipath propagation due to the presence of buildings and infrastructure, often leading to signal degradation. Conversely, rural environments pose fewer obstacles, typically enabling longer ranges and more stable signals.

Given the above, evaluating the real-world performance of LoRa communication in diverse spatial conditions is a crucial step toward optimizing node placement and network design in LoRa-based systems.

The objective of this study is to evaluate the communication range and signal parameters of LoRa technology, focusing on RSSI and SNR, and to compare the results obtained in urban and rural environments.

2. Theoretical Background

LoRa is a low-power, long-range wireless communication technology designed for Internet of Things (IoT) applications, particularly those requiring infrequent transmission of small amounts of data. It is based on chirp spread spectrum (CSS) modulation, which employs frequency-modulated pulse signals—known as chirps—for data transmission. This approach ensures high resistance to noise and interference within the communication channel and enables reliable reception even at low signal levels [2].

LoRa operates in unlicensed Industrial, Scientific, and Medical (ISM) frequency bands. The quality and characteristics of the link depend on several key parameters. One of the most important is the Spreading Factor (SF), which determines the number of chips per symbol. A higher SF allows for greater communication range and improved interference resistance, but at the cost of reduced data transmission speed. In practice, SF values typically range from SF7 to SF12 [3].

Another critical parameter is Bandwidth (BW), with commonly used values of 125 kHz, 250 kHz, and 500 kHz. The combination of SF and BW defines the data rate, which can range from approximately 0.3 kbps to 50 kbps depending on the configuration. Using a wider bandwidth enables higher data throughput, while a narrower bandwidth increases receiver sensitivity, which is beneficial for achieving longer transmission distances. The maximum receiver sensitivity of LoRa devices can reach as low as −137 dBm, which is significantly better compared to other wireless technologies [6].

Link quality is assessed using parameters such as the Received Signal Strength Indicator (RSSI) and the Signal-to-Noise Ratio (SNR). RSSI represents the total power of the received signal, expressed in dBm, and includes both the useful signal and noise. Typical RSSI values for LoRa systems range from −40 dBm (strong signal) to −120 dBm (very weak signal). For a more accurate assessment of link quality, SNR is used. It expresses the ratio between the useful signal and noise in decibels (dB). Positive SNR values (e.g., +10 dB) indicate good link quality, while negative values (e.g., −10 dB) suggest a significant impact of noise and potential information loss [7].

As the distance between devices increases, signal degradation occurs, negatively affecting both RSSI and SNR. RSSI decreases due to propagation losses, while SNR is reduced as a result of increased background noise, signal reflections, and environmental obstacles.

For this study, Heltec WiFi LoRa 32 microcontrollers were used. These devices integrate an ESP32 processor, a built-in LoRa SX1276 chip, and an OLED display. Figure 1 shows the LoRa 32 module with pin configuration.

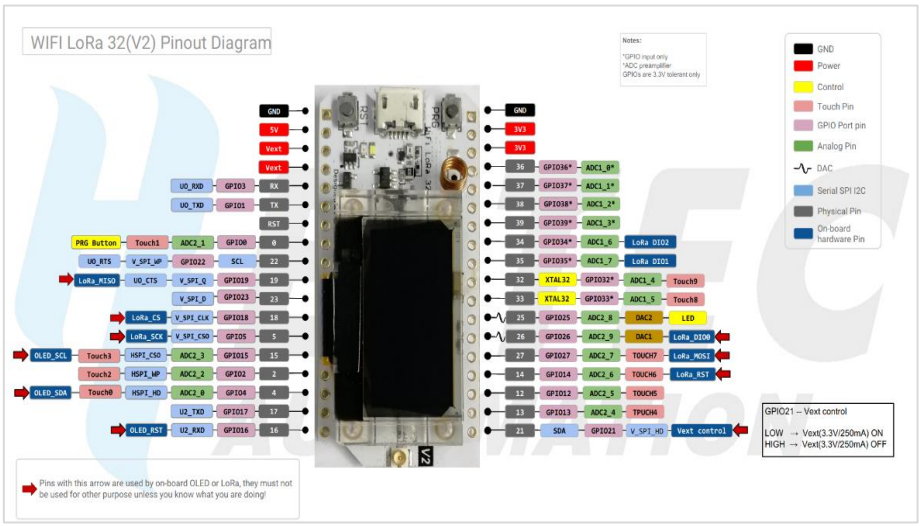

Figure 1. WiFi LoRa 32 module with pin configuration [8].

The devices support direct (single-hop) communication between nodes without the need for LoRaWAN infrastructure.

Table 1. Specifications of the WiFi LoRa 32 module.

Category	Specification
Microcontroller	ESP32 (dual-core 32-bit MCU + ULP core)
LoRa Chip	SX1276/SX1278
USB Interface	Micro USB with voltage regulator, ESD protection, short-circuit protection, and RF protection
Power Supply & Battery	SH1.25-2 interface, integrated Li-ion battery management system (charging, discharging, protection, automatic power switching)
OLED Display	0.96" OLED (128×64 pixels), used to display status, errors, battery voltage, etc.
Network Connectivity	Built-in WiFi, Bluetooth, and LoRa communication
Antennas	Metal spring antenna (2.4 GHz) for WiFi and Bluetooth; IPEX (U.FL) interface for LoRa antenna
USB-to-Serial Chip	CP2102 – enables serial communication and program uploading
Development Environment	Supports Arduino IDE
Power Consumption	Low power consumption, standby current ≤ 800 µA

For visualization and analysis of communication data, the open-source application Meshtastic was utilized. Meshtastic is designed for straightforward configuration of LoRa devices and field testing. This application enables real-time monitoring of parameters such as RSSI, SNR, distance, GPS location, and transmitted messages via a Bluetooth connection with a smartphone. An additional advantage is the ability to export data for further analysis. For these reasons, Meshtastic was selected as the tool that facilitates

simple and efficient testing of LoRa communication in various spatial environments without the need for additional network infrastructure [9].

3. Experimental Analysis

To evaluate the range and stability of LoRa communication under real-world conditions, tests were conducted in controlled field scenarios using off-the-shelf LoRa devices and an application for their configuration and monitoring. The focus was on direct communication between nodes (single-hop), without intermediary devices, and without utilizing LoRaWAN network infrastructure.

The tests were performed using Heltec WiFi LoRa 32 V2 development boards. The Meshtastic mobile application was employed for configuring communication parameters and monitoring network performance. This app enables Bluetooth connectivity with the devices, configuration of communication profiles, as well as access to real-time communication data.

All devices were configured with the "Long range–slow" communication profile, which automatically activates high spreading factor values and lower bandwidth to maximize range and link sensitivity. The selected frequency band was 433 MHz, part of the unlicensed ISM frequency bands, known for better signal propagation through obstacles compared to higher frequency bands.

Measurements were conducted in two distinct spatial contexts:

- *Rural environment*: an open area with minimal interference, favorable for establishing direct line-of-sight (LOS) between nodes.
- *Urban environment*: an area characterized by a significant number of buildings, streets, and other physical obstacles that influence signal reflection, absorption, and diffraction of radio waves.

At each location, three LoRa nodes were used — one stationary node (H1) fixed at a predetermined point, and two mobile nodes (H2, H3), which gradually moved away from the stationary node following a predefined route. Communication between nodes was monitored in real-time via the Meshtastic application, which displayed parameters such as RSSI, SNR, and GPS location. All relevant data were automatically recorded in logs within the application — GPS coordinates in the "Position Log" and RSSI and SNR values in the "Signal Metrics Log." These records were subsequently utilized for signal analysis depending on distance and environment type.

Data for analysis were collected every 50 meters from the stationary node up to a total distance of 1000 meters. Thereafter, testing continued with increased intervals ranging from 100 to 200 meters to determine the maximum distance at which a connection between the stationary and mobile nodes could be maintained. This approach enabled detailed analysis of signal behavior at shorter distances as well as testing the maximum communication range under real-world conditions.

The distance between GPS coordinates is calculated using the Haversine formula, shown in Equation (1), which accounts for the curvature of the Earth's surface and provides the result in meters:

$$d = 2r * \arcsin\left(\sqrt{\sin^2\frac{\Delta\varphi}{2} + \cos(\varphi_1) * \cos(\varphi_2) * \sin^2\frac{\Delta\lambda}{2}}\right) \quad (1)$$

Where:
$d -$ distance between points in meters
$r -$ Earth's radius (approximately 6371 km)
$\varphi_1, \varphi_2 -$ latitudes of the two points in radians
$\Delta\varphi -$ difference in latitudes (in radians)
$\Delta\lambda -$ difference in longitudes (in radians)

At each measurement point, RSSI and SNR values were recorded as key indicators of signal quality. Measurement conditions were kept consistent across both test environments to enable direct comparison between results from urban and rural scenarios.

As a final step, the movement of mobile devices in both environments (rural and urban) will be visualized on Google Maps to provide a clearer depiction of the route and measurement points, thereby offering a graphical insight into the test route structure and the spatial distribution of the collected data.

The results obtained in this study provide valuable insight into the range, stability, and sensitivity of the LoRa link when using predefined communication profiles, without requiring additional programming or firmware modification. The data analysis facilitates the evaluation of the suitability of such a system for deployment in real-world IoT scenarios where simple and reliable communication is essential.

4. Analysis of results

This chapter presents and interprets the results of measuring RSSI and SNR parameters depending on the distance between nodes in different physical environments – rural and urban. The analysis aimed to identify patterns of LoRa connection behavior in real operating conditions, to assess the stability of communication, and the impact of the environment on its quality. The tests were organized in two phases: the first in a rural environment, and the second in an urban environment. Based on the collected data, a series of analyses was performed that included individual graphical representations of changes in RSSI and SNR values for each mobile node, as well as comparisons between environments.

4.1 Rural environment

The first phase of testing was conducted in a rural environment. The movement of mobile nodes H2 and H3 was organized according to a predetermined route, while node H1 was static. Measurements were made every 50 meters up to 1000 m, and thereafter at intervals of 100–200 m, to determine the ultimate range (Figure 2).

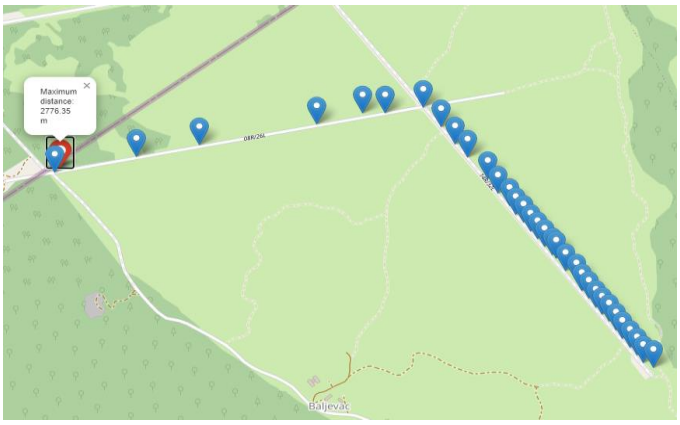

Figure 2. Movement and measurement points in the rural environment.

The maximum distance from the stationary node that was reached by testing in the rural environment is approximately 3 km (Figure 2).

4.1.1 Analysis of the H2 node in the rural environment

Analysis of the measured SNR and RSSI values for node H2, which followed a predefined route in the rural environment, reveals a gradual degradation of signal quality corresponding to the increasing distance from the stationary node. In the initial segment of the test, up to approximately 300 meters, SNR values remained positive (reaching up to 4.0 dB), while RSSI ranged between −103 dBm and −111 dBm, indicating stable and high-quality communication. Beyond this distance, the signal parameters began to exhibit a downward trend. SNR values entered the negative range (e.g., −2.5 dB at 348 m, −5.0 dB at 490 m), reflecting increased noise presence relative to the signal. RSSI values in this segment ranged from −111 dBm to −116 dBm, still within the functional link threshold, though approaching a critical point. In the final phase of the analysis, between 700 m and 1000 m, a more pronounced signal degradation was observed. SNR consistently remained negative (down to −7.25 dB), while RSSI stabilized within the range of −111 dBm to −116 dBm (Figure 3). Despite this, the connection remained established without complete signal loss, confirming the high resilience of LoRa technology against signal degradation in open, less obstructed environments.

The obtained results confirm the expected behavior of the LoRa signal in rural settings — relatively stable communication over considerable distances with a gradual decrease in link quality. Based on the

observed values, it can be concluded that node H2 maintains a functional connection with the base node up to approximately 1 km, demonstrating its suitability for IoT systems that require long-range and low power consumption.

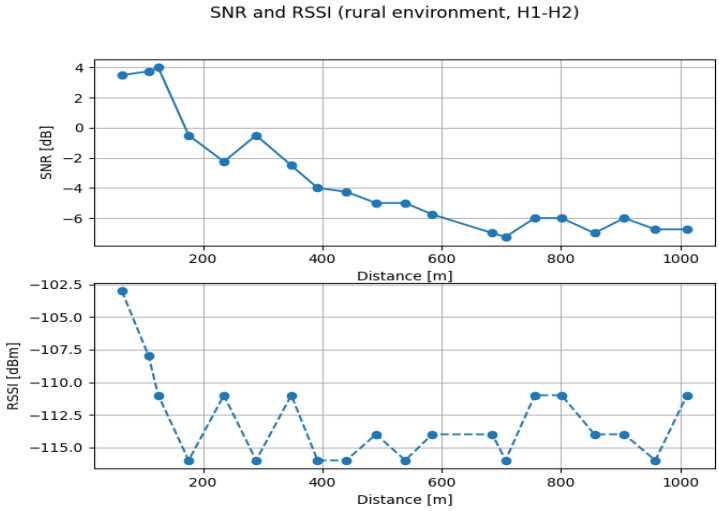

Figure 3. SNR and RSSI parameters in the rural environment (H2 node).

4.1.2 Analysis of the H3 node in the rural environment

Based on the data obtained for node H3 in a rural environment, it can be concluded that the LoRa communication signal was stable and reliable up to approximately 200 meters, where high SNR values (from 7.00 dB to 5.00 dB) and very favorable RSSI values (from –55 dBm to –76 dBm) were recorded. After that point, there is a sharp deterioration in the quality of the connection – already at 250 m, the SNR drops to –2.50 dB, and the RSSI to –111 dBm. In subsequent measurements, the SNR values mainly remain in the negative range, ranging from –2.75 dB to –8.75 dB, while the RSSI shows a continuous decline, reaching minimum values of –116 dBm between 500 and 950 meters of distance. However, despite these values, communication remained possible, which confirms the system's resistance to signal degradation in undisturbed rural conditions. The LoRa link between H3 and the stationary node H1 shows stability up to approximately 200 m, and functionality up to over 1 km, albeit with significantly reduced signal performance, Figure 4.

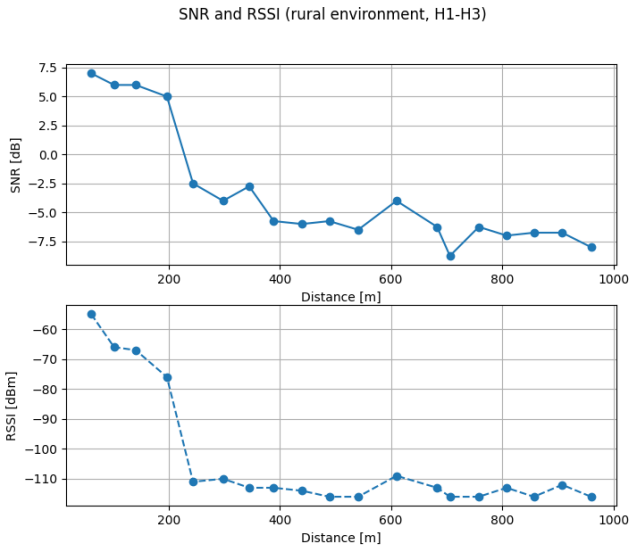

Figure 4. SNR and RSSI parameters in the rural environment (H3 node).

4.2 Urban environment

The second phase of testing was implemented in an urban environment, where mobile nodes H2 and H3 followed a predefined route, with measurements at selected points, and the movement was also displayed on a Google map (Figure 5).

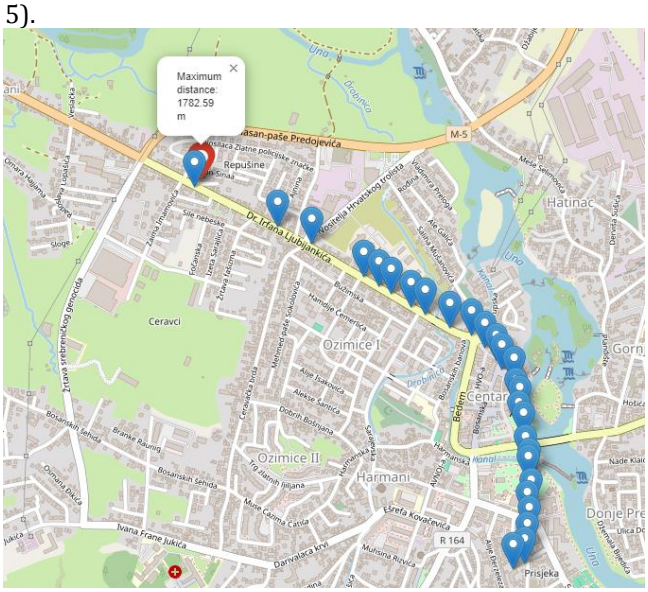

Figure 5. Movement and measurement points in the urban environment.

The maximum distance from a stationary node achieved in urban testing is approximately 1.8 km (Figure 5).

4.2.1 Analysis of the H2 node in the urban environment

Data analysis for the H2 node in an urban environment shows a noticeable impact of the physical environment on the degradation of LoRa connection quality. At initial distances of up to 200 meters, SNR values are high and stable (between 7.00 dB and 6.25 dB), while RSSI ranges from –65 dBm to –72 dBm, indicating an exceptionally good connection quality. However, as the distance increases, both parameters gradually decrease. After 300 meters, a noticeable decrease in SNR values to around 5.00 dB is noticeable, while RSSI reaches –85 dBm. Although they are still within acceptable limits, further distance contributes to accelerated signal degradation. Already at 500 m, SNR drops to 4.50 dB, and RSSI to –95 dBm, while after 600 m there is a sudden transition of SNR values into the negative range. At 800 m, an SNR of –3.00 dB was recorded, and at distances beyond 850 m, the values decreased to –8.50 dB (SNR) and –118 dBm (RSSI), Figure 6. This progressive degradation indicates the significant influence of urban obstacles, such as buildings and other structures, which cause reflections, absorption, and signal losses. Although communication was achievable up to 1 km, the reliability of the connection decreased significantly after 700 m. The obtained results confirm the limitations of LoRa communication in urban conditions and indicate the need for careful planning of node positioning to ensure network continuity.

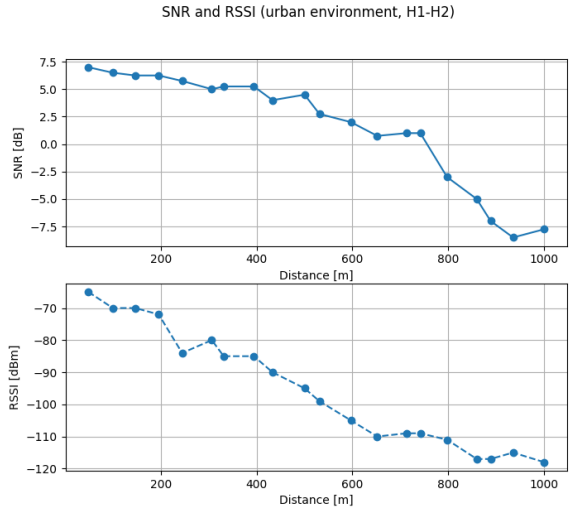

Figure 6. SNR and RSSI parameters in the urban environment (H2 node).

4.2.2 Analysis of the H3 node in the urban environment

Analysis of the performance of the H3 node in an urban environment reveals a pronounced drop in connection quality already at short distances, which confirms the sensitivity of the LoRa signal to urban interference. At the beginning of the test, up to about 200 meters, the SNR values are relatively stable and positive (from 6.25 dB to 5.00 dB), while the RSSI drops from –69 dBm to –85 dBm, which still allows reliable communication. However, already at a distance of 250 m, oscillations occur, where the SNR remains around 5.00 dB, and the RSSI varies between –82 dBm and –88 dBm. After 400 m, the SNR values show a drop of up to 3.50 dB, and the RSSI reaches –103 dBm, which indicates the beginning of more pronounced link degradation. The drop after 500 m is particularly significant, where the SNR goes into the negative range — the values range from –3.00 dB to –12.00 dB, while the RSSI varies between –109 dBm and –125 dBm. These values indicate severe signal degradation and limited communication reliability at that range. The lowest recorded values of –12.00 dB for SNR and –125 dBm for RSSI occur already at about 900 m distance, Figure 7. Although the H3 node achieved communication up to 1 km in urban conditions, the connection quality dropped significantly after 500 m. The faster drop compared to the H2 node may be a result of positioning or differences in antenna orientation, but generally confirms that the density of obstacles and reflective surfaces of the urban environment have a strong negative impact on LoRa communication.

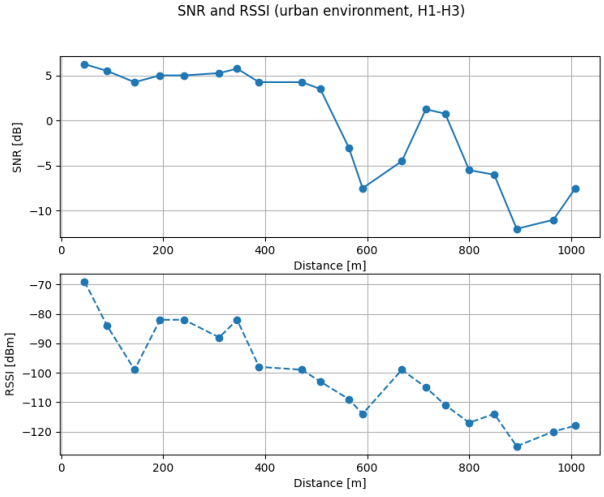

Figure 7. SNR and RSSI parameters in the urban environment (H3 node).

4.3 Comparison of rural and urban results

To evaluate in detail the influence of the environment on the quality of LoRa communication, a comparison of the results for the H2 node in rural and urban environments was performed, comparing the values of the key parameters: SNR and RSSI to the distance from the stationary H1 node. It is noticeable that the SNR values in rural environments at the initial distances (up to 250 m) have a slightly higher level compared to the urban environment, and then there is a gradual decrease in both scenarios. However, the urban scenario shows an earlier and steeper decrease in SNR values, which indicates a greater presence of noise and interference due to physical obstacles. At distances over 700 m, the SNR in urban environments turns into negative values earlier than in rural environments, which indicates a degradation of the connection quality. In the case of RSSI values, the differences are even more pronounced — rural environments retain the signal better at greater distances. In urban environments, the RSSI decline is much faster, with values below -110 dBm already after 600–700 m, while in rural environments, similar values appear only after 900 m. These results confirm that physical obstacles and electromagnetic interference in urban environments significantly affect the strength and quality of LoRa signals.

Figure 8a shows a graphical representation of the SNR parameter values for node H2 in both environments, which visualizes the differences in the signal-to-noise ratio at different distances.

Figure 8b shows a graph for the RSSI parameter, where a more pronounced drop in signal strength in an urban environment due to the presence of obstacles and interference is clearly visible.

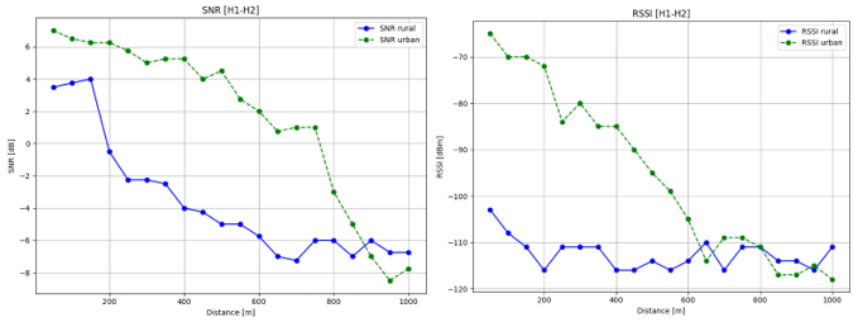

Figure 8. Analysis of SNR (a) and RSSI (b) in urban and rural environments for H2 nodes.

Analysis of the performance of the H3 node in rural and urban environments shows marked differences in the stability and range of the LoRa connection due to different environmental conditions. In the rural environment, the H3 node achieved reliable communication with stable SNR values (up to 7.00 dB) and low RSSI (from –55 dBm), especially at distances up to 200 m. Although oscillations in both parameters are recorded after 250 m, the connection remains functional up to a distance of about 2.8 km, with final SNR values of around –10.75 dB and RSSI of –119 dBm recorded. This indicates the resilience of the signal in an environment without significant obstacles. Conversely, in urban conditions, the H3 node records a significantly faster decline in connection quality. SNR values become negative after 500 m, and RSSI drops below –110 dBm at distances greater than 600 m. The lowest recorded values are –12.00 dB for SNR and –125 dBm for RSSI, with maximum communication achieved up to approximately 1.8 km. This comparative analysis confirms that rural environments are significantly more suitable for LoRa communication, with more stable signal parameters and greater range, while urban environments significantly affect the degradation of the connection due to reflection, absorption, and obstacles.

Figure 9a shows a graphical representation of the value of the SNR parameter for node H3 in both environments, which visualizes the differences in the signal-to-noise ratio at different distances.

Figure 9b shows a graph for the RSSI parameter, where a more pronounced drop in signal strength in an urban environment due to the presence of obstacles and interference is clearly visible.

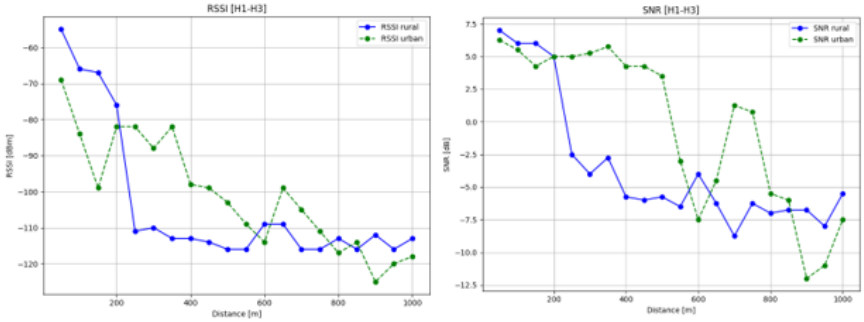

Figure 9. Analysis of SNR (a) and RSSI (b) in urban and rural environments for H3 nodes.

These results confirm that for node H3, as well as for H2, the urban environment introduces additional challenges for LoRa communication, especially in terms of signal quality and its reading at longer distances.

5. Discussion and conclusion

The conducted research aimed to examine the communication characteristics of LoRa technology in real-world conditions, comparing rural and urban environments, using direct (single-hop) communication between Heltec LoRa 32 devices. Using the Meshtastic application, it is possible to easily set and monitor communication parameters, as well as automatically record key connection quality indicators — RSSI and SNR.

The results obtained show that the physical environment significantly affects the performance of the LoRa connection. In a rural environment, where obstacles are minimal, the signal remains stable and readable even at distances greater than 2.5 km, with acceptable values of RSSI and SNR parameters. On the other hand, in urban conditions, due to the presence of buildings, streets, and reflective surfaces, the signal is significantly more exposed to interference, which causes an earlier drop in connection quality and limits the range to a maximum of about 1.8 km.

As expected, the analysis of the results for both mobile nodes (H2 and H3) confirmed that signal degradation occurs earlier in urban conditions and with greater dynamics, while the rural environment allows for a more gradual decline and greater reliability of communication over longer distances. In particular, it was observed that the SNR values approach the negative range faster in the urban scenario, while the RSSI drops more sharply after 600 m, which confirms the high sensitivity of the link to obstacles.

The results of this research indicate that, although LoRa technology has a high potential for communication in environments without additional infrastructure, the range and reliability depend significantly on the terrain characteristics. This confirms the need for careful planning when implementing IoT solutions in different environments, especially in the context of urban applications, where in certain cases the use of network protocols such as LoRaWAN or multipath (mesh) architectures could be considered to preserve the continuity of the connection.

In order to improve the system, one of the next research projects could include testing multipath networks, as well as the use of different communication profiles and higher gain antennas.

Also, the use of an automated system for analyzing log data and its integration with mapping services (e.g., Google Maps API) could further improve the accuracy and efficiency of performance evaluation. Analysis of device energy efficiency during communication and longer periods of operation, as well as testing in complex topographic areas (e.g., mountainous areas or closed industrial complexes), represent potential directions for future research.

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Comparative analysis of cryptographic algorithms with aspects of performance and cryptographic robustness

Amel Toroman[1] and Ranko Babić[2]

[1]University of Bihać, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina
[2]Faculty of Technical Sciences, University of Priština in Kosovska Mitrovica, Kosovska Mitrovica, Serbia

*E-mail: amel.toroman@unbi.ba

Abstract This paper analyzes various cryptographic algorithms through practical implementation and comparative testing of their efficiency and security. Three basic categories are covered: symmetric algorithms (AES, DES, 3DES, Blowfish, RC4), asymmetric encryption (RSA) and cryptographic hash functions (SHA-256, SHA-3, MD5). In addition to the basic encryption and decryption functions, the paper integrates a component for generating pseudorandom strings, which is used to evaluate algorithms under controlled conditions. Special emphasis is placed on measuring the encryption and decryption times, which was used as a key criterion for comparing performance. Data visualization enabled the identification of time differences between algorithms, with symmetric algorithms showing significantly better results in terms of speed, while asymmetric and hash algorithms stood out in terms of data security and integrity. The results obtained indicate the importance of carefully selecting a cryptographic algorithm in accordance with the context of application - whether high efficiency, resistance to attacks or a compromise between these two factors is required. The proposed methodology can also be used as a basis for further evaluation of new or combined encryption schemes in the field of computer security.

1. Introduction

In the modern digital age, data security is one of the key challenges of information technology. The exponential growth in the amount of sensitive information transmitted and stored over the Internet requires increasingly sophisticated approaches to data protection. Cryptography, as the foundation of computer security, enables the protection of data integrity, confidentiality, and authenticity through various algorithmic approaches - including symmetric, asymmetric, and hash functions. Each of these cryptographic systems has different strengths and weaknesses in terms of security, processing speed, and applicability in real systems [1].

In recent years, research has focused on evaluating the performance of various cryptographic algorithms in practical environments. Numerous studies compare the performance of algorithms such as AES, DES, RSA, and SHA variants to identify optimal choices for specific use cases, such as IoT devices, mobile applications, and distributed systems [2], [3]. Particular attention is paid to encryption and decryption times, memory consumption, and resistance to various attacks, including brute-force and side-channel analysis.

Symmetric algorithms (AES, DES, 3DES, Blowfish) are characterized by excellent performance in encryption and decryption, while RC4 and similar algorithms have been gradually abandoned due to security flaws. Al Tamimi and Okolie & Adetoba note that AES systematically outperforms DES and 3DES in speed and memory requirements [4], while Aisha Atib Tijjani and Abdullahi Isa confirm the superiority of symmetric methods in processing large [5]. Asymmetric algorithms such as RSA facilitate key distribution, but require significantly more computing power [1].

Hash functions such as SHA 256, SHA 3 and MD5 do not allow the recovery of the original data, but serve to check the integrity. SHA 3 is additionally resistant to collisions, although it is slightly slower than SHA 2 on certain platforms [6].

One of the key elements of any modern cryptographic implementation is the use of quality random number generators (Random Number Generators - RNG), which play a key role in generating keys,

initialization vectors and one-time values. The poor quality of the RNG directly threatens the security of the cryptographic system. A recent study by Toroman, A. and associates [7] "Random number generators based on models of random access memory and configured gas", published in the Journal of Circuits, Systems and Computers, makes a significant contribution to this field. The paper analyzes RNG models based on physical principles and RAM architectures, which show high entropy and statistical reliability, which opens up space for their effective application in modern data protection systems.

This paper aims to unify the theoretical basis and empirical analysis of the performance of various cryptographic algorithms through the development and testing of application models. Using a wide range of algorithms, including AES, DES, 3DES, Blowfish, RC4, RSA and multiple hash functions, the paper provides a comprehensive assessment of their processing speed and reliability. Special emphasis is placed on the use of modern RNG models in the process of generating input data, as well as on comparing the results depending on the type of algorithm (symmetric, asymmetric, hash). The intention is to create a tool that allows for a practical assessment of processing speed, integrity and trade-offs between security and performance depending on the type of algorithm. Based on the developed application, representative symmetric, asymmetric and hash cryptographic algorithms are implemented in this paper, and through it, encryption and decryption times are measured and benchmark test results are presented to compare their performances.

2. Cryptographic algorithms and basics of security

Encryption is a technique for protecting information so that only authorized parties can interpret the data. Encryption allows the transformation of plaintext into ciphertext that humans cannot read.

Not only in the digital age, codes have been widely used throughout history. We categorize codes according to some characteristics they have or according to their use. They are mainly divided into two different types; classical and modern classes. The most common and widely used in the digital world is the modern class. Precisely because of their dynamic and static cryptographic techniques, they pave the way for more detailed classes, symmetric and asymmetric ciphers.

An indicator of a good cryptographic algorithm is the encryption and decryption time. Encryption time is the time it takes to convert plaintext to ciphertext. The length of the encryption process is determined by the key size, the size of the plaintext block, and the mode of operation. For a system to be fast and responsive, the encryption time should be short. Decryption time is the time it takes to retrieve plaintext from ciphertext. For a system to be fast, it should be shorter than the encryption time.

Through practical implementation of work on symmetric algorithms, asymmetric and hash functions, encryption and decryption times for the same input structure, i.e. content, were measured, and a performance analysis was provided.

While with symmetric encryption we have only one key for encrypting and decrypting data, with asymmetric encryption we use two different keys. We use a public key for encryption and a private key for decryption. Although public and private keys are different, they are related to each other, so we call them a key pair. DES, 3DES, AES, and Blowfish are members of the class of symmetric key block ciphers, and we will describe and compare them in this paper.

2.1 Symmetric algorithms

Symmetric encryption is also called single-key cryptography. It uses a single key. In this encryption process, the recipient and sender must agree on a single secret (shared) key. Given a message (called plaintext) and a key, encryption produces unintelligible data that is approximately the same length as the plaintext. Decryption is the opposite of encryption and uses the same key as encryption [8].

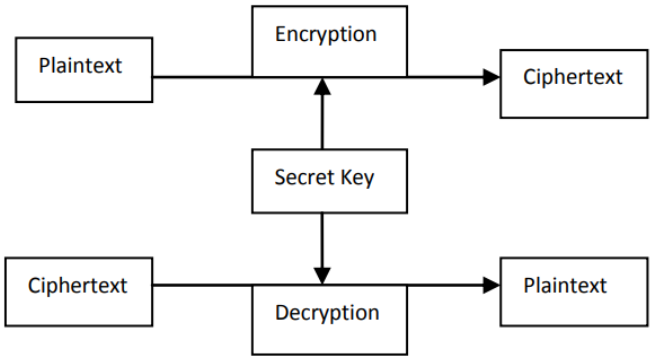

Figure 1. Cryptography with a symmetric key [8].

As can be seen in Figure 1, symmetric cryptography uses a single shared key to encrypt and decrypt messages. The sender uses this key to convert the original message into ciphertext, while the recipient uses the same key to restore the message to its original form. The key must be secretly shared between the sender and recipient before communication occurs, because compromising the key compromises the entire system.

Symmetric algorithms use the same key to encrypt and decrypt data. Although they are efficient and fast, they require a secure channel for key exchange. The following are included in the analysis:

- DES (Data Encryption Standard) – an outdated standard with a 56-bit key, today considered insecure.
- 3DES (Triple DES) – DES is applied three times; more secure, but slower.
- AES (Advanced Encryption Standard) – block size 128 bits, keys 128/192/256 bits; it is considered very safe.
- Blowfish – 64-bit block, variable key length (up to 448 bits); known for speed.
- RC4 – stream cipher; not recommended today due to vulnerabilities.

Table 1. Technical characteristics of symmetric algorithms [9].

	DES	**3DES**	**Blowfish**	**AES**
Key length	56 bits	112 or 168 bits	448 bits	128, 192, or 256 bits
Block size	64 bits	64 bits	64 bits	128 bits
Year of development	1975	1978	1993	2000
Speed	Slow	Slow	Fast	Fast
Security	Not sure enough	Not sure enough	Safe enough	Safe enough
Structure	Feistel	Feistel	Feistel	Replacement Permutation
Time required to check all possible keys at a speed of 50 billion keys per second	400 days	800 days	~3200 days	$5x10^{21}$ days

As can be seen from Table 1, DES is not secure enough. It is precisely because of the short key length and brute force attacks that it can be easily cracked. Therefore, although 3DES is another alternative, it is not secure enough either.

Although Blowfish is a good alternative, its block size is not as large as AES. We consider AES to be the successor to DES as a symmetric key encryption algorithm for organizations. It accepts different key sizes, 128, 192, or 256 bits. It is efficient in both software and hardware. We can see the efficiency of AES when

we look at the time it takes to check all possible keys at a rate of 50 billion keys per second. Its results are much better than other encryption algorithms, even when using a key size of 128 bits.

2.1.1 DES algorithm

DES was developed by IBM and is based on a design by Horst Feistel. It was one of the widely used and publicly available cryptographic systems when it was first released. Although it was first introduced in the 70s, it was later adopted by the National Institute of Standards and Technology (NIST). It is a symmetric key algorithm for encrypting digital data. It has a block size of 64 bits and uses a Feistel network as a structure. It is slow and not used in software. He had a great influence on the progress of cryptography. However, it is not secure for applications due to the short 56-bit key length. In 1999, distributed.net cracked the DES key in 22 hours and 15 minutes. After such events, NIST withdraws this algorithm as a standard. 3DES emerged after a vulnerability in DES [11].

2.1.2 3DES algorithm

Triple DES, 3DES, or TDES, is officially a triple data encryption algorithm. It is a symmetric block cipher that applies the DES algorithm three times to each block. It has a block size of 64 bits and a key length of 112 or 168 bits. It also uses a Feistel network because it is based on DES [12]. Due to modern cryptographic and supercomputing techniques, 3DES also has some serious vulnerabilities, like DES. Therefore, NIST deprecated DES and 3DES for new applications in 2017, and for all applications by 2023. As a result, AES came on the scene and replaced these encryption algorithms.

2.1.3 3DES algorithm

AES is a type of cipher that protects data from malicious parties. It is currently one of the strongest encryption algorithms available. Because AES combines speed and security, it allows us to continue our online activities without any interruptions. Because AES uses the same key to encrypt and decrypt data, it is also a symmetric type of encryption. There are three types of AES encryption key lengths: 128, 192, and 256 bits. Each key length has different possible key combinations. It has a different structure than other encryption algorithms, using a substitution and permutation network [11]. Although the key length of the AES encryption method varies, the block size is fixed at 128 bits or 16 bytes.

2.1.4 Blowfish algorithm

Blowfish is another symmetric key encryption technique designed by Bruce Schneier in 1993 as an alternative to the DES encryption algorithm. Therefore, it is significantly faster than DES and provides a good encryption rate. Its key length is 446 bits, which is much better than DES and 3DES [12]. Therefore, it is more difficult to crack the Blowfish key. It also has a block size of 64 bits. It can also be used in software. However, AES is gaining more attention today, and Schneier recommends Twofish as an alternative to Blowfish. It has a free license and is available for all uses.

2.2 Asymmetric algorithms

Asymmetric cryptography uses two keys: a public key for encryption and a private key for decryption, which allows for secure key transfer. It is also called public-key cryptography. Therefore, it uses two keys: a public key, which is known to the public, which is used for encryption, and a private key, which is known only to the user of that key, which is used for decryption. The public and private keys are related to each other by some mathematical means [8].

In other words, data encrypted with one public key can only be encrypted with the corresponding private key. The process of asymmetric key cryptography is shown in Figure 2.

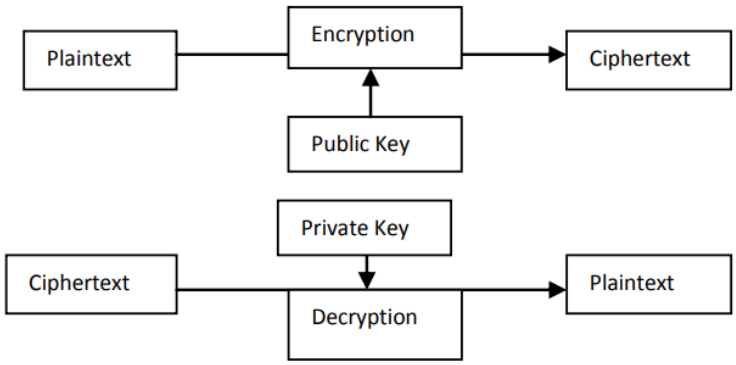

Figure 2. Cryptography with an asymmetric key [8].

As can be seen in Figure 2, asymmetric key cryptography uses two different but mathematically related keys – a public key and a private key. The public key is freely distributed and used to encrypt a message, while only the corresponding private key, which remains secret, can be used to decrypt that message. This provides confidentiality because only the owner of the private key can read the encrypted message. In addition, if the sender signs the message with his private key, the recipient can verify the authenticity and integrity of the message using the sender's public key – thus providing a digital signature.

2.2.1 RSA algorithm

The RSA (Rivest-Shamir-Adleman) encryption algorithm is an asymmetric encryption algorithm that is widely used in many products and services. Asymmetric encryption uses a pair of keys that are mathematically related to encrypt and decrypt data. A private and a public key are created, with the public key available to everyone, and the private key is a secret known only to the creator of the key pair. With RSA, either the private or public key can encrypt data, while the other key decrypts it. This is one reason why RSA is the most widely used asymmetric encryption algorithm [13].

The ability to encrypt with either a private or public key provides a number of services to RSA users. If a public key is used for encryption, the private key must be used to decrypt the data. This is perfect for sending sensitive information over a network or internet connection, where the recipient of the data sends the sender of the data their public key. The sender of the data then encrypts the sensitive information with the public key and sends it to the recipient. Because the public key encrypted the data, only the owner of the private key can decrypt the sensitive data. Therefore, only the intended recipient of the data can decrypt it, even if the data is intercepted in transit.

Figure 3 shows the working principle of the RSA algorithm.

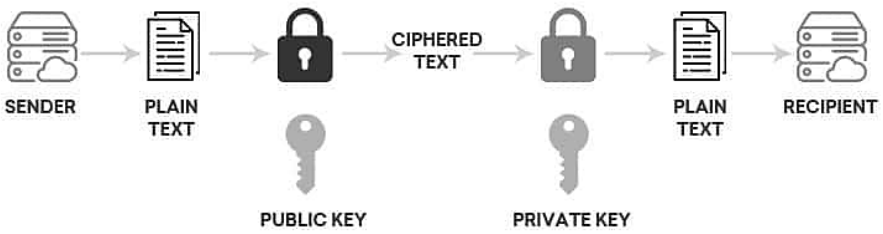

Figure 3. The working principle of the RSA algorithm [13].

Another method of asymmetric encryption with RSA is private key encryption. In this example, the sender of the data encrypts the data with his private key and sends the encrypted data and his public key to the recipient of the data. The recipient of the data can then decrypt the data with the sender's public key,

thereby verifying that the sender is who he claims to be. With this method, the data could be intercepted and read in transit, but the real purpose of this type of encryption is to prove the identity of the sender. If the data were intercepted and altered in transit, the public key would not be able to decrypt the new message, and the recipient would know that the data had been altered in transit [13].

The technical details of the RSA algorithm are based on the idea that it is easy to generate a number by multiplying two sufficiently large prime numbers, but factoring that number back into the original prime numbers is extremely difficult. Public and private keys are created from two numbers, one of which is the product of two large prime numbers. Both use the same two prime numbers to calculate their value. RSA keys are typically 1024 or 2048 bits long, making them extremely difficult to factor, although 1024-bit keys are believed to be soon to be breakable.

2.3 Hash functions

A hash function takes an input value (for example, a string of characters) and returns a fixed-length value. An ideal hash function has the following properties:

- it is very fast
- can return a huge range of hash values
- generates a unique hash for each unique input (no collisions)
- generates different hash values for similar input values
- generated hash values have no recognizable pattern in their distribution.

Of course, there is no ideal hash function, but each one strives to function as close to ideal as possible. Given that (most) hash functions return values of fixed length and that the range of values is therefore limited, this limitation can be practically ignored. The number of possible values that a 256-bit hash function can return, for example, is approximately equal to the number of atoms in the universe.

Ideally, a hash function should return almost no collisions - that is, no two different inputs generate the same hash value. This is especially important for cryptographic hash functions: hash function collisions are considered a vulnerability.

So, a hash function should generate unpredictably different hash values for any given input value.

There are several hash functions in wide use. All were designed by mathematicians and computer scientists. During further research, some were found to have weaknesses, although all were considered good enough for non-cryptographic applications.

Digest algorithms generate one-way hash values that are used for integrity verification:

- SHA 256 (output 256 bits) – very secure, widely used.
- SHA 3 (256 bits) – a newer version, resistant to attacks such as length extension.
- MD5 (128 bits) – today considered undecipherable due to collisions.

Table 2. Basic characteristics of hash functions [10].

Algorithm	Output (bits)	Security
SHA-256	256	High
SHA-3	256	High
MD5	128	Crypto compromised

2.3.1 SHA-256 algorithm

The SHA-256 algorithm belongs to the SHA-2 family of algorithms, where SHA stands for Secure Hash Algorithm. This algorithm was published in 2001. The main motive for publishing this algorithm was to create a successor to the SHA 1 family, and it was developed by the NSA and NIST because the SHA-1 family was losing its strength due to brute force attacks.

As the name suggests, 256 means that the generated hash value remains 256 bits every time, regardless of the size of the plaintext, and always remains 256 bits [14]. The most important characteristics of SHA-256 that distinguish it from others are:

- *Digest length*: This means that the hash length should be based on the naming convention, for example, 256 bits are used in SHA-256, 512 bits in SHA-512, and so on.
- *Irreversible quality*: This means that functions like SHA-256 are irreversible, meaning you should not get the clear text when accessing the digest and you should not get the original value by passing it through a hash function.

2.3.2 SHA-3 algorithm

SHA-3 (Secure Hash Algorithm 3) is known as the newest member of the SHA family of secure hashing algorithms, and was published by NIST in 2015. SHA-3 differs when we look at the internal structure of SHA-3 because the structure of MD-5 is different from SHA-1 and SHA-2. SHA-3 is designed to allow a "random mapping" of a given string of binary data into a "message digest" of fixed size, and SHA-3 also helps to achieve multiple security properties [14]. The characteristics of the SHA-3 algorithm are:

- *Digest sizes*: The size of the SHA-3 algorithm digest is arbitrary.
- *Speed*: The speed of the SHA-3 algorithm is 12.6 cpb on an x86-64 computer, which is equivalent to the speed of the SHA-256 algorithm.

The SHA3–256 algorithm is a variant with equal applicability to the earlier SHA-256, with the former requiring slightly more time to compute than the latter.

2.3.3 MD5 algorithm

MD (Message Digest) algorithms are another set of hash functions, but are generally considered less secure than SHA algorithms..

MD5 is a widely used algorithm that generates a 128-bit hash value. However, it is no longer recommended for cryptographic purposes due to its vulnerabilities. MD5 is prone to collision attacks, where two different inputs can produce the same hash value, making it unreliable for verifying data integrity..

Thus, the MD5 hash function produces a 128-bit hash value. It was designed for use in cryptography, but over time, vulnerabilities were discovered, and it is no longer recommended for that purpose. However, it is still used for database partitioning and calculating checksums to validate file transfers [14].

MD5 is commonly used to generate checksums to verify the integrity of files. By calculating the MD5 hash value of a file before and after transfer, the checksums can be compared to determine whether the file has been modified or corrupted.

In certain scenarios, MD5 is used for data deduplication, which involves identifying and removing duplicate copies of data. By calculating the MD5 hash value of pieces of data or files, duplicates can be identified and removed, optimizing storage space. Using MD5 for cryptographic purposes, such as storing passwords or digital signatures, is strongly discouraged due to its vulnerability to collision attacks.

2.4 Random Number Generators (RNG)

The need for random numbers arises in many programs. Various cryptographic algorithms and protocols require a certain sequence of random bits in certain steps (e.g., public key generation, random bit generation in the authentication process, keys in digital signatures and seals, etc.). Therefore, the application of random numbers can be divided into two categories: cryptography and computer simulation. Both categories require that the random numbers used resemble "true" random numbers as closely as possible. It is important to note that in reality, random numbers occur only in natural phenomena and situations that are impossible to predict. However, in practice, hardware and/or software solutions are used that result in the obtained numbers being more or less random. The characteristic of randomness cannot

be formally defined. Given that the very occurrence of a sequence of random numbers represents an unpredictable, stochastic system, it is impossible to say whether a sequence of numbers is random or not. Each test tries to determine whether there are any regularities in the input sequence that statistically should not occur, and the sequence is accepted or rejected as "random".

The paper used a Python pseudo-random number generator, but the reference paper [7] showed an advanced model that combines RAM memory randomness and physical gas fluctuation, providing significantly higher entropy and security. This model is considered promising in modern cryptography because it avoids the determinism of classical pseudorandom number generators. Random number generators can generally be divided into two categories: "true" random number generators and pseudorandom number generators.

2.4.1 TRNG random number generators

This category includes generators that generate random numbers based on natural phenomena, i.e. the source of the random numbers is non-deterministic (a random number in a sequence is independent of its predecessor) [15]. These generators are entirely or mostly circular in nature, and their implementation is sensitive and expensive, and their applications are limited. In addition, the generation of numbers can be slow, and the circuit itself is prone to failures. Therefore, such generators are more often used in simulation applications.

2.4.2 PRNG random number generators

This type of generator is essentially a function that, based on initial conditions, produces an output sequence of pseudorandom numbers. The input to the generator (seed) must be “truly” random and is obtained from a “truly” random number generator (e.g., the time of the system clock). Once the initial conditions are determined, each number in the sequence can be predicted, which leads to deterministic characteristics of the generator, and the resulting numbers are called pseudorandom. The entire sequence can be reproduced only with knowledge of the initial conditions, so if the sequence needs to be reproduced, it is sufficient to preserve only the initial conditions [15].

Interestingly, in tests, pseudorandom numbers sometimes perform better than random numbers obtained from physical sources. By carefully choosing the generator and initial conditions, the deterministic methods used can be disguised, and the output sequence takes on many of the characteristics of random numbers. In general, pseudorandom number generators are faster, easier to implement, and more portable.

3. Development and implementation of software solutions-application

The developed software solution, or application, is a functional tool for testing and evaluating various cryptographic algorithms, with the aim of comparing them based on performance and applicability in modern security systems. The application was created in the Python programming language, using the Tkinter library for developing a graphical user interface (GUI) and the PyCryptodome cryptographic package for implementing cryptographic operations. The application is designed to allow the user not only to select an algorithm, but also to interactively evaluate its performance.

The primary purpose of the application, as shown in Figure 4, is to enable users to select one of the supported algorithms from the area of symmetric, asymmetric and hash cryptography, encrypt and decrypt the entered text, and compare the performance of individual algorithms through the display of encryption and decryption times. Additionally, functionality is implemented to generate pseudo-random input data using a built-in RNG, enabling a standardized test framework for evaluation.

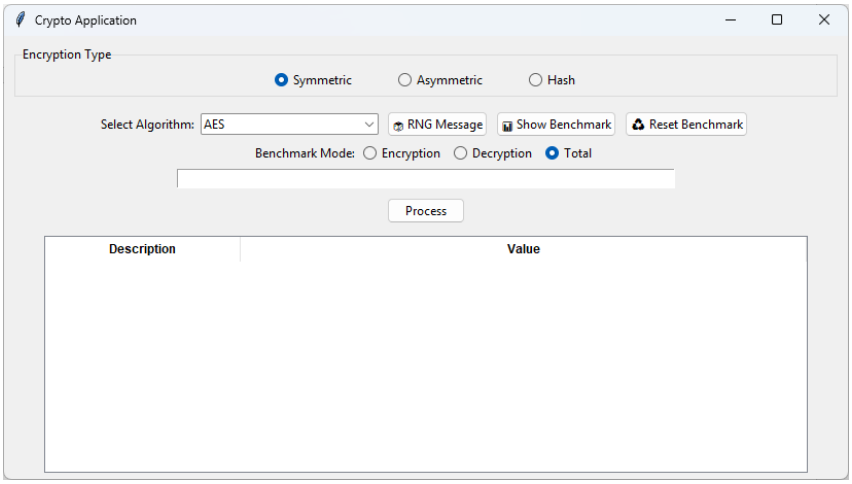

Figure 4. Graphic representation of the created application without data entry.

Figure 4 shows the application without data entry, while Figure 5 shows the application with an example of data entry and the results obtained.

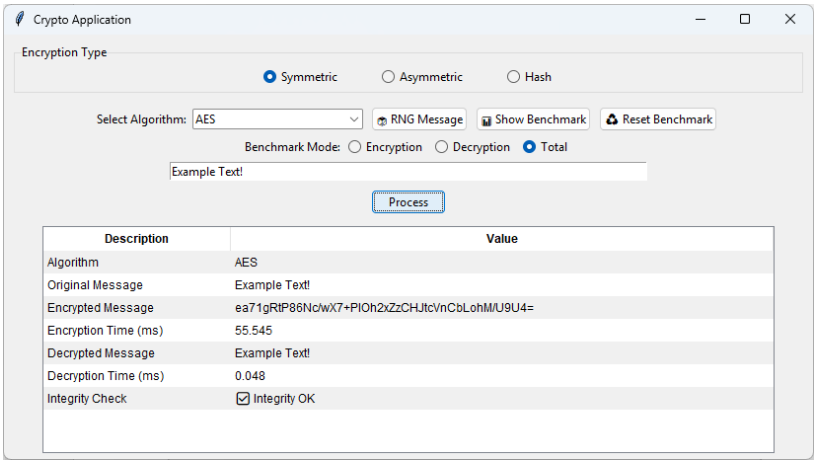

Figure 5. Graphic representation of the created application with data entry.

As mentioned, the following tools and libraries were used to implement the application:

- *Python 3.11+* – basic programming language.
- *Tkinter* – a standard library for creating GUI applications.
- *PyCryptodome* – library for symmetric and asymmetric cryptographic functions (AES, DES, Blowfish, RSA, etc.).
- *Matplotlib* – for a graphical representation of the execution time of the algorithm in the form of a diagram.
- *Hashlib* – standard Python library for hash functions (SHA-256, SHA-3, MD5).

The developed application allows the user an intuitive and efficient way of working with a wide range of cryptographic algorithms. Each component of the application has been carefully designed with the aim of enabling a clear understanding of the encryption and decryption process, as well as a realistic measurement of the performance of each algorithm. Each functionality is detailed below:

a) Choosing the type of cryptography and algorithm

At the beginning of work, the user chooses one of the three basic categories of cryptography:

- Symmetric cryptography - algorithms like AES, DES, Triple DES, Blowfish and RC4.

- Asymmetric cryptography – RSA algorithm.
- Hash functions – SHA-256, SHA-3 and MD5.

Once the user selects a category, the application automatically displays a list of available algorithms within that group in a drop-down menu, reducing the possibility of error and facilitating navigation. This functionality is dynamic and responds to changes in the algorithm type selection.

b) Entering and generating input text

The user has two options for entering data:

- Manual text entry – in a special field, the user can enter any text they want to encrypt, Figure 5.
- Automatic random number generation (RNG) - by clicking the "🎲 RNG message" button, the application uses the built-in random number generator to create an alphanumeric string of a defined length (16 bits). This functionality allows you to test algorithms on the same, repeatable data.

c) Data encryption

Clicking the "Process" button starts the encryption process. In the background, the application measures the exact encryption time using *time.perf_counter(),* with high precision. A corresponding class from the *PyCryptodome* library is used for each algorithm, and the standard *hashlib* library is used for hash functions.

The encryption process depends on the algorithm:

- CBC mode and initialization vector (IV) are used for symmetric algorithms.
- RSA uses a public key.
- For hash algorithms, a hash value is obtained that is irreversible.

d) Data decryption

If the algorithm is reversible (everything except hash functions), decryption is automatically started after encryption. Using the same instance of the algorithm (or regenerated using RSA/AES), the application decrypts the ciphertext and measures the decryption time in milliseconds.

The decrypted result is then compared with the original text and based on this, the status is displayed:

- ✅ Integrity is correct if the texts match.
- ❌ It's not a coincidence, if there is a difference.

e) Display of results

All key results are displayed in a table with two columns: "Description" and "Value." Information includes:

- Selected algorithm
- Original text
- Encrypted text (Base64)
- Encryption time (ms)
- Decrypted text (if any)
- Decryption time (ms)
- Integrity check result

For better clarity, every other row of the table is marked with a different color.

f) Benchmarking performanse

The application automatically records the encryption and decryption times for each algorithm. By clicking the "📊 Show benchmark" button, the user is presented with a bar graph in which the comparison of execution times for all algorithms executed from the selected category is seen. Benchmark regimes include:

- Encryption only
- Decryption only

- Total (both times overlap)

Two different colors (e.g. light red and light green) are used for the overlay, so the visualization remains clear even in case of overlap.

g) Reset benchmark data

The user can reset all collected data using the "♻ Reset Benchmark" button, which allows for a fresh start and comparison under new testing conditions.

4. Test results and performance analysis

The performance evaluation of the implemented cryptographic algorithms was conducted through a series of experiments using the developed application. The tests included the use of symmetric, asymmetric and hash algorithms with two types of input text:

1. manually entered message by user
2. an automatically generated pseudo-random message using a random number generator, 16 characters long.

Performance measurement is based on total encryption and decryption time expressed in milliseconds (ms), with additional message integrity checks where applicable. The data is visually displayed using bar charts directly from the application.

4.1 Testing symmetric encryption

The symmetric algorithms included in the analysis are: AES, DES, 3DES, Blowfish and RC4. Each of them uses the same key for encryption and decryption, which allows for efficient data processing.

The first way to test symmetric encryption is to enter arbitrary text. The text entered was: **Development and Modernization of Production (RIM)**, and the resulting encryption and decryption times, depending on the selected algorithm, are shown in Table 3.

Table 3. Symmetric encryption test results (user-entered message).

Algorithm	Encryption time (ms)	Decryption time (ms)
AES	0.111	0.042
DES	0.212	0.056
3DES	0.132	0.049
Blowfish	0.158	0.091
RC4	0.138	0.024

Figure 6 also shows a graphical representation of the obtained results shown in Table 3, for testing symmetric encryption with user-entered message.

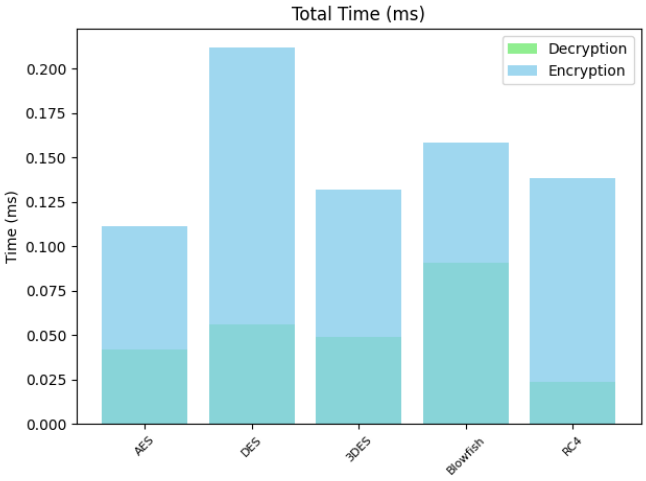

Figure 6. Display of symmetric encryption test results (user-entered message).

As can be seen in Figure 6, among the tested symmetric algorithms, AES achieves the shortest encryption time (0.111 ms), confirming its optimization and efficiency in modern security applications. 3DES and RC4 show similar encryption times (0.132 ms and 0.138 ms), although 3DES internally uses three consecutive DES processes. Blowfish, with 0.158 ms, although efficient, shows slightly higher latency, while DES is the slowest (0.212 ms), which is consistent with its outdated architecture and limited key length. Overall, the results confirm that AES is the most efficient choice, while DES and 3DES are increasingly being avoided due to their poorer performance and security weaknesses.

Decryption was faster for all algorithms compared to encryption, with RC4 in particular having the shortest decryption time recorded (0.024ms), reflecting its simple key structure. AES again dominates the secure algorithms with a time of 0.042 ms, while 3DES (0.049 ms) and DES (0.056 ms) are slightly slower, but still within the acceptable range. Blowfish has the longest decryption time (0.091 ms), which may be due to the more complex key layout and S-box structure. Overall, AES offers the best balance of decryption and encryption, while RC4 offers the fastest speed - albeit at the cost of compromised security.

Another way to test symmetric encryption is by using an automatically generated pseudorandom message using a 16-character random number generator. The generated random text is: **XcRftflKSQhcW54f**, and the resulting encryption and decryption times, depending on the chosen algorithm, are shown in Table 4.

Table 4. Symmetric encryption test results (automatically generated text input, RNG)

Algorithm	Encryption time (ms)	Decryption time (ms)
AES	0.126	0.043
DES	0.211	0.089
3DES	0.199	0.093
Blowfish	0.150	0.088
RC4	0.166	0.021

Figure 7 also shows a graphical representation of the obtained results shown in Table 4, for testing symmetric encryption by inputting automatically generated text, RNG.

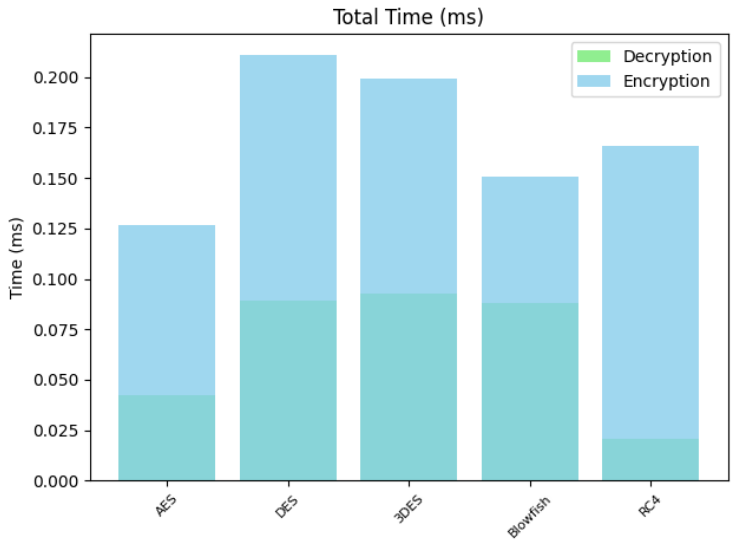

Figure 7. Display of symmetric encryption test results (automatically generated text input, RNG).

According to the results shown in Figure 7, the most efficient algorithm in terms of encryption time is again AES, with a time of 0.126 ms, confirming its reputation as a fast and modern algorithm designed for high efficiency. The slowest algorithm in this test is DES, with an encryption time of 0.211 ms, which is expected given its outdated architecture and shorter key length. 3DES, although more secure than DES, also shows a high encryption time (0.199 ms), because it implements triple DES functions. Blowfish is located between the modern AES and classic DES algorithms, with an encryption time of 0.150 ms, while RC4, which was previously the fastest, now has a slightly longer encryption time of 0.166 ms, which may depend on the specific input and current execution conditions.

Decryption is still the fastest operation for all algorithms, with RC4 being the fastest at just 0.021 ms, consistent with its simple algorithm stream structure. AES again shows exceptional performance in decryption, with a time of 0.043 ms, confirming itself as one of the most efficient algorithms in both directions. Decryption times with Blowfish, 3DES, and DES are roughly similar (from 0.088 ms to 0.093 ms), indicating a somewhat more complex process of recovering the plaintext from the ciphertext, but still within acceptable limits. However, DES and 3DES maintain their place as slower compared to modern algorithms, while AES and RC4 remain the optimal choices in terms of performance.

4.2 Testing asymmetric encryption

In the asymmetric encryption category, the RSA algorithm was tested, which uses a pair of keys (public and private).

Due to the complexity of operations with large numbers, RSA shows significantly higher processing time compared to symmetric algorithms, which is also noticeable in the results (Figure 8, Figure 9). However, its advantage lies in key distribution and security.

As with symmetric encryption, two tests were performed. The first way to test asymmetric encryption is to enter arbitrary text. The text entered was: **Development and Modernization of Production (RIM)**, and the resulting encryption and decryption times for the RSA algorithm are shown in Table 5.

Table 5. Asymmetric encryption test results (user-entered message)

Algorithm	Encryption time (ms)	Decryption time (ms)
RSA	80.194	2.512

Figure 8 also shows a graphical representation of the obtained results shown in Table 5, for testing asymmetric encryption with message input by the user.

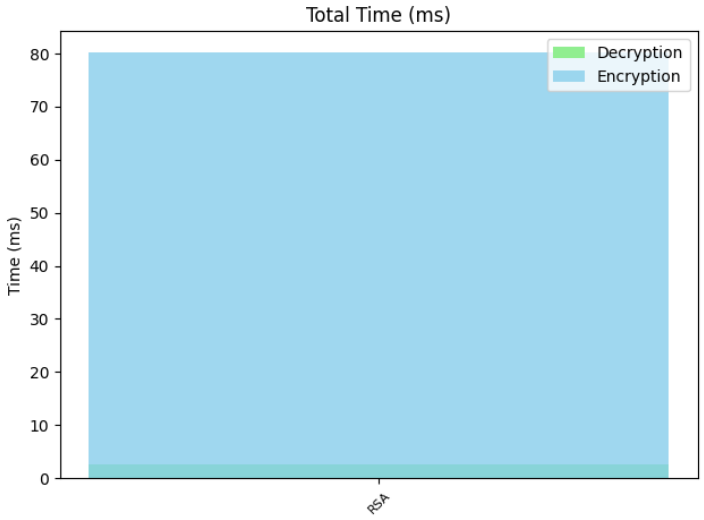

Figure 8. Display of asymmetric encryption test results (message entered by the user).

The results in Figure 8 clearly show that RSA is significantly slower in the encryption process compared to symmetric algorithms. The encryption time is 80.194 ms, which is a consequence of the very nature of asymmetric cryptography, where larger keys (in this case 2048-bit) and more complex mathematical operations, such as exponentiation in modular arithmetic, are used. The RSA algorithm is not primarily designed for efficient processing of large numbers of messages, but for secure key distribution and protection of small amounts of data (e.g. hashes or session keys). Therefore, its high latency in encryption is not an unexpected result, but a typical characteristic of asymmetric systems.

In contrast to the encryption process, RSA decryption shows a significantly lower time, with a result of 2.512 ms. This difference stems from the way the key values are generated - where the public exponent (used for encryption) is often chosen as a small number for speed, while the private exponent (used for decryption) is larger and optimized for use with additional techniques, such as the Chinese Remainder Theorem (CRT). Despite this, RSA decryption is still slower compared to decryption with symmetric algorithms, but given the level of security it provides and the specific use cases, the performance is satisfactory for its intended purpose.

Another way to test asymmetric encryption is by using an automatically generated pseudo-random message using an RNG mechanism of 16 characters. The generated random text is: **XcRftflKSQhcW54f**, and the resulting encryption and decryption times for the RSA algorithm are shown in Table 6.

Table 6. Test results of asymmetric encryption (automatically generated text input, RNG)

Algorithm	Encryption time (ms)	Decryption time (ms)
RSA	0.547	2.662

Figure 9 also shows a graphical representation of the obtained results shown in Table 6, for testing asymmetric encryption by inputting automatically generated text, RNG.

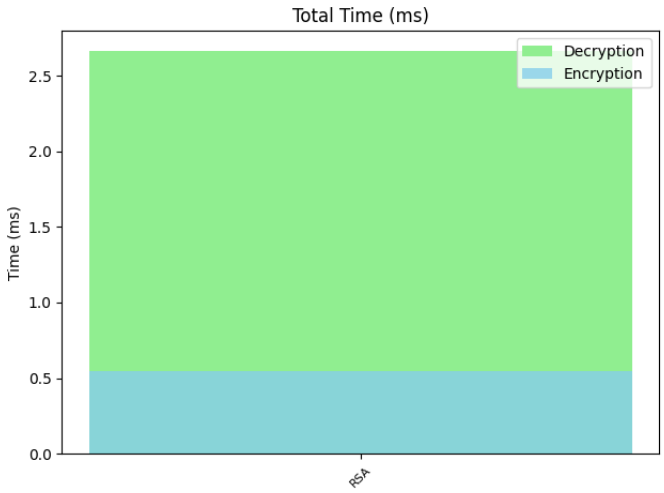

Figure 9. Display of asymmetric encryption test results (automatically generated text input, RNG).

According to the results shown in Figure 9, the RSA algorithm achieved an encryption time of 0.547 ms, which is extremely fast for an asymmetric cryptographic algorithm. This value may be due to the use of an optimized public key with a small exponent (most commonly e=65537), which is often used to speed up encryption. Since RSA is primarily designed to protect small messages (or session keys), this time indicates an efficient implementation of encryption when the input message is short, as is the case in most cryptographic applications.

On the other hand, the decryption time is 2.662 ms, which is about four times slower than the encryption time. This result is in line with expectations for RSA, as the decryption process uses a private exponent, which is many times larger and requires more computing resources. However, the value of 2.662 ms is still an acceptable result in the context of applications where sparse and small data is decrypted, such as session keys in protocols such as TLS or PGP.

4.3 Testing hash encryption

The hash algorithms tested in this application are: SHA-256, SHA-3 and MD5. Unlike the previous ones, hash algorithms are not reversible - there is no decryption process. They are used to create a message fingerprint (digital digest) and check integrity. As with symmetric and asymmetric encryption, two tests were performed. The first way to test hash encryption is to enter arbitrary text. The text entered was: **Development and modernization of production (RIM)**, and the encryption and decryption times obtained by the hash encryption algorithms are shown in Table 7.

Table 7. Hash encryption test results (message entered by user)

Algorithm	Encryption time (ms)	Decryption time (ms)
SHA-256	0.427	N/A
SHA-3	0.080	N/A
MD5	0.171	N/A

Figure 8 also shows a graphical representation of the obtained results shown in Table 5, for testing asymmetric encryption with message input by the user.

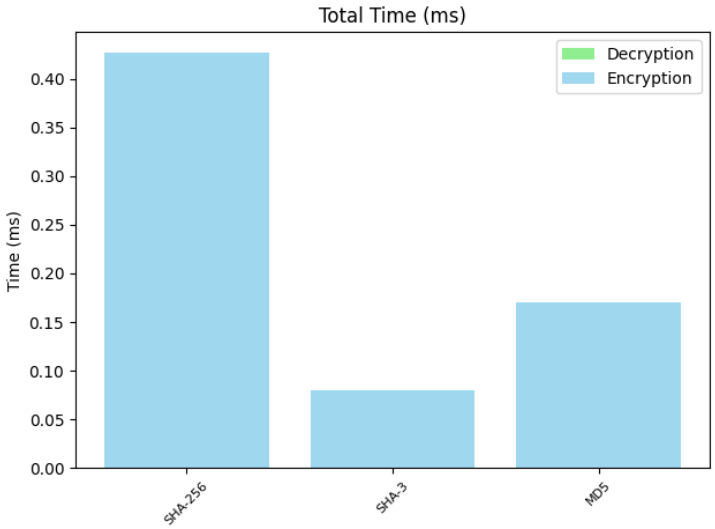

Figure 10. Display of hash encryption test results (message entered by the user).

As can be seen from Figure 10, testing the hashing algorithms SHA-256, SHA-3, and MD5 recorded encryption (hashing) times without decryption capabilities, as they are one-way functions. The SHA-256 algorithm showed the longest encryption time of 0.427 ms, which is expected given its high security and complexity. On the other hand, SHA-3 proved to be the fastest, with a hashing time of only 0.080 ms, thanks to the optimized Keccak core. MD5, although cryptographically outdated, achieved a solid encryption time of 0.171 ms, which confirms its speed, but not its security reliability.

For all hash algorithms, the decryption values are marked as N/A (Not Applicable), which is exactly correct. Hash algorithms are one-way - they generate a unique digest of the input message, but do not allow for a return to the original text. This feature makes them suitable for data integrity verification, digital signatures, and secure password storage.

Another way to test hash encryption is with an automatically generated pseudo-random message using the RNG algorithm of length 16 characters. The generated random text is: **XcRftflKSQhcW54f**, and the obtained results are shown in Table 8.

Table 8. Hash encryption test results (automatically generated text input, RNG)

Algorithm	Encryption time (ms)	Decryption time (ms)
SHA-256	0.065	N/A
SHA-3	0.035	N/A
MD5	0.039	N/A

Figure 11 also shows a graphical representation of the obtained results shown in Table 8, for testing hash encryption by inputting automatically generated text, RNG.

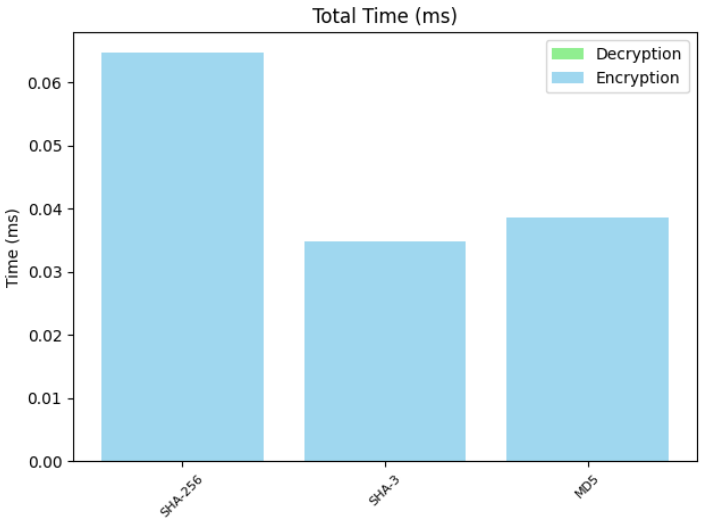

Figure 11. Display of hash encryption test results (automatically generated text input, RNG).

The obtained hash algorithm test results, shown in Figure 11, show high encryption (hashing) speed for all tested functions, where, as expected, the decryption time is marked as N/A because hash algorithms represent one-way functions and are not reversible. In this test, SHA-256 had the longest encryption time of 0.065 ms, which is consistent with its more complex structure and longer output hash length (256 bits), which provides a higher level of security. SHA-3, which uses the Keccak construction, achieved a faster time of 0.035 ms, confirming its efficiency and optimized design. The fastest among the tested was MD5, with an encryption time of 0.039 ms, which is still significant, although this algorithm is now considered insecure due to known collision vulnerabilities. Overall, all algorithms showed very short execution times, making them suitable for tasks where the speed of data verification is critical, such as digital signatures, authentication, and integrity control.

5. Discussion and conclusion

This paper presents a detailed analysis of the performance of different cryptographic algorithms through a developed Python software solution that enables simple evaluation of symmetric, asymmetric and hash functions for encryption and decryption, with the integration of a pseudorandom number generator for generating different input strings. This enables the robustness and effectiveness of algorithms to be tested under different conditions, which further contributes to the understanding of their applicability in real security scenarios.

The created software solution offers users the option of selecting an algorithm, entering a message or generating random text, as well as viewing the results through tabular displays and graphic visualizations, which enables a clear interpretation of the performance of each algorithm.

The results show that symmetric algorithms, especially AES, achieve the best efficiency in encryption and decryption time, making them suitable for processing large amounts of data. The asymmetric RSA algorithm, due to its more complex structure, requires significantly more time for encryption, while hash algorithms have recorded very short execution times; where SHA-3 represents a good balance between security and speed, while MD5, despite its speed, has security flaws.

These results confirm that the choice of algorithm depends on the specific requirements and application context – symmetric algorithms are best suited for fast data processing, asymmetric for secure key management and digital signatures, while hash functions are best used for integrity checks and authentication.

Also, the integration of the RNG mechanism further enriched the tests by providing more realistic input data, which is crucial for valid assessment of security and performance.

As a direction for future research, it is proposed to expand the application by including modern algorithms such as *ChaCha20* and *AES-GCM*, as well as *quantum-resistant solutions*, with the implementation of additional visual and statistical analysis methods, as well as increasing the number of test sets and parallelizing test execution.

This paper represents the basis for further development of tools for efficient and interactive evaluation of cryptographic algorithms, which contributes to improving security and optimization in digital systems.

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Experimental analysis and modelling of the influence of concrete ingredients on compressive strength

Damir Hodžić, Elma Veladžić, Sanin Džidić and Edis Softić

University of Bihać, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina

E-mail: damir.hodzic@unbi.ba

Abstract. The compressive strength of concrete depends on a large number of factors, the most important of which are: type, grade and proportion of cement, quality and proportion of aggregates, water-cement ratio, influence of admixtures, method of installation, method of curing of concrete. Estimating the compressive strength of concrete, as well as estimating the final strength of concrete based on early test results, is practically important for any type of load-bearing concrete structures. However, it is not directly known to what extent the composition of individual concrete ingredients can actually affect the compressive strength. This paper presents experimental analysis of ingredients of concrete: cement, water, aggregates and superplasticizer on the compressive strength of concrete. The aim of the research is to determine the functional dependence of the compressive strength of concrete on the concrete ingredients, based on the test results, and thus to estimate the compressive strength. For the purpose of this thesis, 32 cube concrete samples have been produced, i.e. 16 different concrete mixtures with two samples each. As the concrete mix is made on the basis of a previously determined mix design, two already defined concrete mixes were used. The remaining 14 mixes were obtained by varying the amounts of ingredients, so as to make all possible combinations of four ingredients. The production, curing and testing of samples were done according to EN 12390. The results obtained by the experiment were statistically processed, and a mathematical model was developed, which is used to obtain the assumption of compressive strength with satisfactory accuracy in relation to input values of the parameters.

1. Introduction

Concrete is a composite material, produced artificially, which is composed of at least three ingredients: aggregate, cement and water. In this mixture, aggregate acts as a filler, cement as a binder, and water enables the chemical reaction of cement. Without any of these three ingredients, there is no concrete.

For specific reasons (e.g. high or low temperatures at the concrete installation site, workability, etc.), additives or concrete additives can also be added to the concrete mixture, which are classified as air entraining agents, setting accelerators or retarders, plasticizers, superplasticizers, sealants, etc., in order to achieve certain specific properties of concrete during the preparation, installation or care of concrete [1].

The most important property of concrete is its compressive strength. Data on the strength of the material is obtained by testing test specimens in presses and other devices by loading them to failure. When testing the compressive strength of concrete, the test specimen is exposed to uniaxial short-term pressure until failure. The load is gradually increased to failure within one to two minutes.

The compressive strength of concrete is influenced by: the standardized strength of the cement used, the water-cement factor and the degree of compaction, the duration of the hardening period from the moment of preparation to the moment of testing, temperature and humidity. Other factors such as the amount of cement used, type of pores, properties of aggregates, shape of aggregate grains and others are of secondary influence.

The method of determining the compressive strength of hardened concrete samples is prescribed by EN 12390-3. The samples are loaded to failure using a pressure testing device specified in EN 12390-4. When testing the compressive strength of concrete, the test body is exposed to uniaxial short-term pressure until failure. The highest load that the sample has endured is recorded and the strength of the concrete sample is calculated. For testing, a compressive strength testing device made in accordance with EN 12390-4 is used. [2]

The sample shall be a cube, roll or core in accordance with the requirements of EN 12350-1, EN 12390-1, EN 12390-2 or EN 12504-1. Excess moisture is wiped from the surface of the sample before placing it in the testing device. Cube-shaped specimens are placed so that the direction of loading is perpendicular to the direction of concrete placement. The sample is centered on the bottom plate to an accuracy of ±1% of the design cube size or the design diameter of the roller samples. A significant number of experiments involve determining the effects of two or more factors. In such cases, the most efficient is to use a factorial design. This method implies that each possible combination of factor levels being analyzed is examined at least once during the experiment.

The most common factorial design is the 2^k factorial design, which is especially useful in the early stages of experimental work when many factors can be examined relatively easily. In the 2^k designation, k denotes the number of factors, and the number 2 is the number of factor levels. This design of the experiment shows the minimum number of experiments that must be conducted with which k factors can be studied in a full factorial design of the experiment. The main purpose of the 2^k factorial design is to obtain a linear regression function with linear terms.

Four input factors (water, cement, aggregate and additive) were selected for the preparation of this work on two levels, i.e. the 2^4 experiment plan. Therefore, 2^4 =16 combinations are possible in order to be able to analyze the mutual influence of all input factors on two levels on the output size, the compressive strength of concrete [3,4].

The input factors and the values of the corresponding input factor levels are presented in Table 1.

Table 1. Input factors with low and high level

	Input factors			
Level	Water [*l*]	Cement [*kg*]	Aggregate [*kg*]	Additive [*l*]
Low	175	350	1822	1,4
High	192	400	1913	2

Treatment combinations are to be arranged according to rules for 2^4 design.

2. Experiment

The experimental part of this work was carried out in the company Đuzelić d.o.o. . Sixteen different mixes were made, each with two cube-shaped samples measuring 15 x 15 x 15 [*cm*]. For economic reasons, 1 [m^3] of concrete for two cubes was not produced, but a recalculated value was produced manually with an increase in the volume of concrete by 20% (due to wastage of material). For the purposes of this research, two already established recipes for concrete C25/30 and C30/37 were chosen. By combining the quantities of concrete ingredients of these two mixtures, the remaining 14 mixtures were obtained [5].

Tables 2 and 3 presentrs the treatment combinations with the corresponding quantities of materials for one cubic meter of concrete, and the calculated quantities for production.

Table 2. Recipe for 1 [m^3] of concrete

Treatment combination	Water [*l*]	Cement [*kg*]	Aggregate [*kg*]	Additive [*l*]
01	175	350	1822	1,4
02	175	350	1822	2,0
03	175	350	1913	1,4
04	175	350	1913	2,0
05	175	400	1822	1,4

06	175	400	1822	2,0
07	175	400	1913	1,4
08	175	400	1913	2,0
09	192	350	1822	1,4
10	192	350	1822	2,0
11	192	350	1913	1,4
12	192	350	1913	2,0
13	192	400	1822	1,4
14	192	400	1822	1,4
15	192	400	1913	2,0
16	192	400	1913	2,0

Table 3. Recipe for one cube 0.15 x 0.15 x 0.15 = 0.003375 [m^3] of concrete

Treatment combination	Water [*l*]	Cement [*kg*]	Aggregate [*kg*]	Additive [*l*]
01	0,59	1,18	6,15	4,70
02	0,59	1,18	6,15	6,75
03	0,59	1,18	6,46	4,70
04	0,59	1,18	6,46	6,75
05	0,59	1,35	6,15	4,70
06	0,59	1,35	6,15	6,75
07	0,59	1,35	6,46	4,70
08	0,59	1,35	6,46	6,75
09	0,65	1,18	6,15	4,70
10	0,65	1,18	6,15	6,75
11	0,65	1,18	6,46	4,70
12	0,65	1,18	6,46	6,75
13	0,65	1,35	6,15	4,70
14	0,65	1,35	6,15	6,75
15	0,65	1,35	6,46	4,70
16	0,65	1,35	6,46	6,75

The production of concrete samples in this experiment was carried out in accordance with EN 12390-2, Figure 1. No damage to the samples was observed during visual inspection.

Figure 1. Samples before compressive strength testing [7]

The compressive strength testing of concrete samples was carried out at the Institute of the Faculty of Technical Engineering, University of Bihać, Figure 2.

Figure 2. Compressive strength testing of concrete samples [7]

A typical satisfactory fracture pattern of a specimen when testing concrete is shown in Figure 3a. It can be seen that all four exposed sides fractured approximately equally, while the sides of the specimen in contact with the slabs have minor damage, Figure 3b.

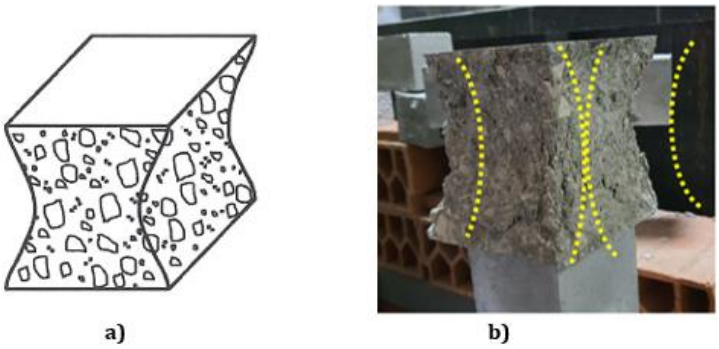

Figure 3. a)typical fracture of concrete specimen, b) actual fracture of specimen [7]

Experimental results of compressive strength are presented in the table 4 with mean value for compressive strength.

Table 4. Experimental results for compressive strength

Treatment combination	Water [*l*]	Cement [*kg*]	Aggregate [*kg*]	Additive [*l*]	Compressive strength [MPa]
01	175	350	1822	1,4	46.89
02	175	350	1822	2,0	48.885
03	175	350	1913	1,4	43.11
04	175	350	1913	2,0	54.445
05	175	400	1822	1,4	66.445
06	175	400	1822	2,0	70
07	175	400	1913	1,4	60.445
08	175	400	1913	2,0	67.335
09	192	350	1822	1,4	42.445
10	192	350	1822	2,0	46.89
11	192	350	1913	1,4	34.445
12	192	350	1913	2,0	39.22
13	192	400	1822	1,4	47.78
14	192	400	1822	1,4	48.225
15	192	400	1913	2,0	43.11
16	192	400	1913	2,0	44.225

The obtained compressive strength values range from 34.445 MPa to 70 [*MPa*].

3. Results and discussion

For the purposes of this work and to confirm the obtained statistical results and obtain a mathematical model of compressive strength, the Design Expert software package was used. For the results of the experiment, the mean value of the compressive strength for two measurements from each repetition was taken.

After adding experimental results first step is to use half-normal plot to visually select effects for two-level factorial design. The half-normal plot allows us to visually distinguish between small effects and large effects which are likely to be statistically significant, Figure 4 [6].

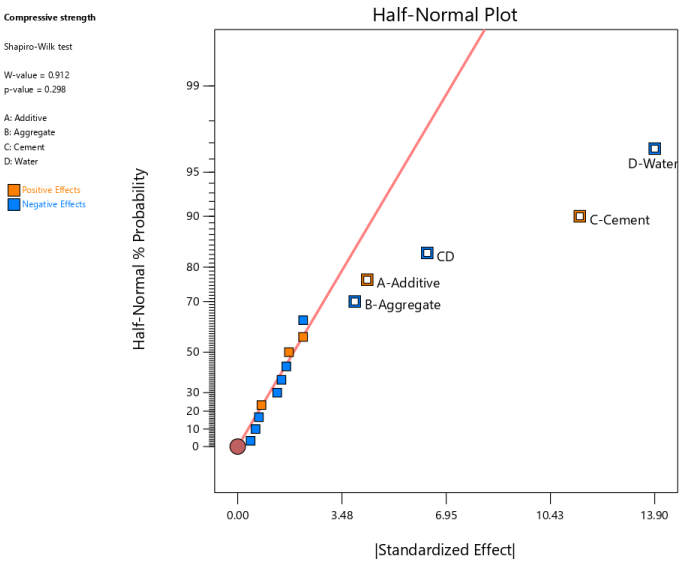

Figure 4. Half-normal plot of effects

To manage model selection for factorial design it can also be used Pareto chart, Figure 5.

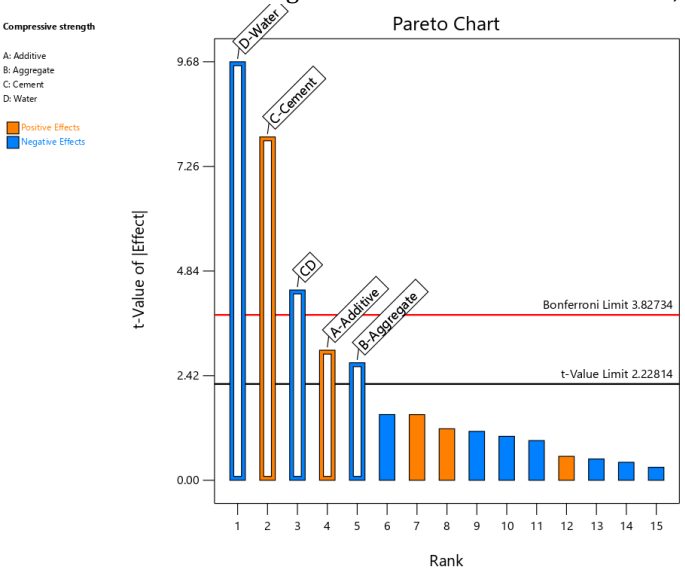

Figure 5. Pareto chart of effects

There are two different *t* limits plotted on the Pareto chart. The highest limit is based on the Bonferroni *t* value. The lower limit is based on standard *t* value. Selected effects that are above the Bonferroni limit are

certainly important and must be left in the model. Effects that are above the *t* limit are possibly important and should be added if they make sense to the experimenter. Effects that are below the t-value limit must not be added to the model.

Now the Analysis of Variance (ANOVA) can be presented like follow, Table 5.

Table 5. ANOVA for selected factorial model

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-value	p-value
Model	1588.59	5	317.72	38.53	< 0.0001
A-Additive	74.63	1	74.63	9.05	0.0132
B-Aggregate	60.94	1	60.94	7.39	0.0216
C-Cement	520.24	1	520.24	63.09	< 0.0001
D-Water	773.05	1	773.05	93.75	< 0.0001
CD	159.74	1	159.74	19.37	0.0013
Residual	82.46	10	8.25		
Cor Total	1671.05	15			

The **Model F-value** of 38.53 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. **P-values** less than 0.0500 indicate model terms are significant. In this case A, B, C, D, CD are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

According to ANOVA final model equation in terms of actual factors can be interepted

Y= -840.55 + 7.19896*A + -0.0428915*B + 2.95657*C + 4.75816*D + -0.0148691*CD

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. According to final model equation predicted values of compressive strength can be calculated and compared to actual experimental values, Table 6.

Table 6. Report on actual and predicted values

Treatment combination	Actual Value	Predicted Value	Residual	Internally Studentized Residuals	Externally Studentized Residuals
01	46.89	48.12	-1.23	-0.544	-0.524
02	48.88	52.44	-3.56	-1.568	-1.712
03	43.11	44.22	-1.11	-0.489	-0.470
04	54.45	48.54	5.90	2.601	4.337
05	66.44	65.85	0.5969	0.263	0.250

06	70.00	70.17	-0.1675	-0.074	-0.070
07	60.45	61.94	-1.50	-0.661	-0.641
08	67.33	66.26	1.07	0.472	0.452
09	42.45	40.54	1.90	0.838	0.825
10	46.89	44.86	2.03	0.894	0.884
11	34.45	36.64	-2.19	-0.966	-0.963
12	39.22	40.96	-1.74	-0.766	-0.749
13	47.78	45.63	2.15	0.948	0.943
14	48.23	49.95	-1.72	-0.758	-0.741
15	43.11	41.72	1.39	0.611	0.590
16	44.23	46.04	-1.82	-0.801	-0.785

Predicted and actual experimental values can be presented in a graph, Figure 5, which helps to detect observations that are not well predicted by the model.

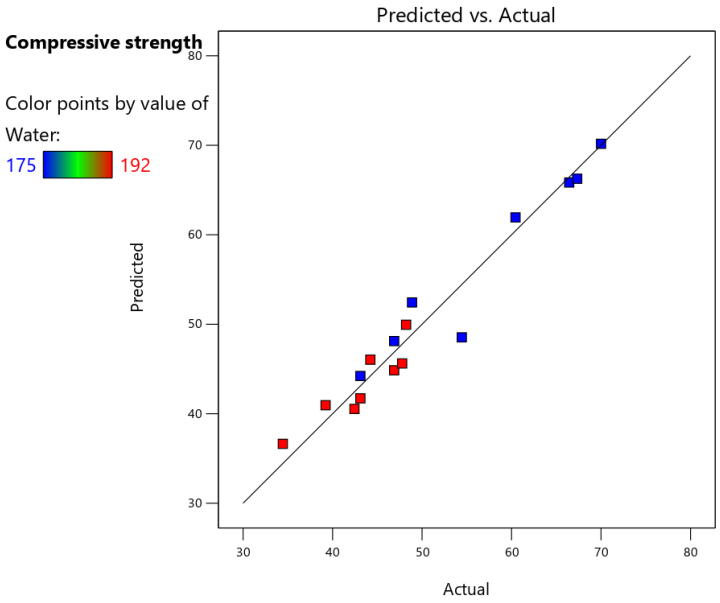

Figure 5. Predicted vs. actual values chart

Figure 6 shows the dependence of compressive strength values on input factors. It is easy to see that with an increase in the value of factors A (Additive) and C (Cement), the compressive strength increases, that is, with an increase in the value of factors B (Aggregate) and D (Water), the compressive strength decreases.

Figure 7 shows the dependence of the compressive strength value on the significant interaction between input factors C (Cement) and D (Water).

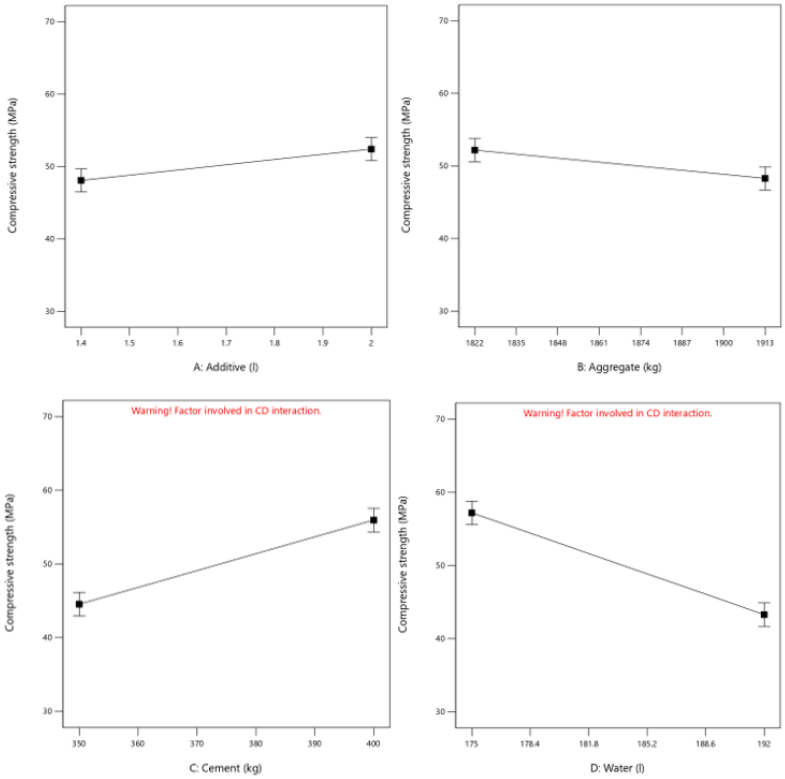

Figure 6. All factors dependance on compressive strength

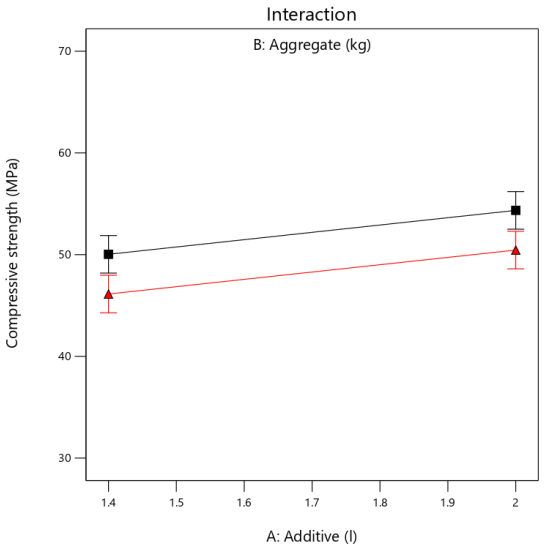

Figure 7. Interaction dependance on compressive strength

3. Conclusion

Design of experiment and its statistical processing significantly speed up and improve the research process and lead to more reliable conclusions, which is why they deserve greater application in industry and academia. In contrast to experimentation, which involves varying the value of one factor while the others are kept at constant values, statistical methods of experiment planning enable the simultaneous variation of several factors, the subsequent analysis of which enables obtaining data on their influence as well as the influence of the interaction of factors.

Since tracking the influence of more than one factor is very complicated to analyze, computer algorithms are needed to facilitate the comparison of multiple factors at once, as well as their interactions.

The use of partial factorial designs can drastically reduce the number of experiments because they ignore first or higher order interactions, depending on the resolution of the design. Often, interactions of a higher order introduce only additional complexity and are not of interest if the investigated process is to be described by a maximally simplified mathematical model. Preliminary experiments select the most significant from a large number of factors, which is why partial factorial plans are widely used in research, development and process improvement in industry.

By statistical analysis of data obtained experimentally by analyzing the results obtained using software, it can be concluded:

- The compressive strength of concrete is significantly influenced by the amount of water, cement, aggregates, additives and the interaction between water and cement.
- The distribution of model values in relation to experimental values is satisfactory.
- Discarding factors that are not significant from the analysis can greatly improve the final model.
- The choice of the appropriate method of modeling any process is of crucial importance for the adequacy of the model.

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Infrared thermography as a tool in civil engineering

Medina Mešić, Damir Hodžić and Fadila Bašić

University of Bihać, Faculty of Technical Engineering, Bosnia and Herzegovina

E-mail: medina.mesic@unbi.ba

Abstract. Thermography is an indispensable tool in modern civil engineering, enabling precise analysis of a structure's thermal characteristics. The use of thermal cameras allows for the rapid detection of temperature anomalies, which is crucial for identifying various issues such as poor insulation, moisture, and water infiltration through structural elements. Additionally, thermal cameras can assist in identifying different structural components of buildings, enhancing safety, and thereby extending the lifespan of structures. Thermography enables non-destructive inspection of buildings, increasing energy efficiency and reducing maintenance costs. The further development of this technology, in synergy with advanced software analysis, is expected to be a key factor in improving the civil engineering industry.

Keywords: thermal camera, buildings, temperature anomalies

1. Introduction

The application of infrared thermography in civil engineering is becoming increasingly important. By visualizing thermal radiation, a wide range of irregularities in buildings can be detected—some of which may be critical to structural integrity. For example, Krstulović and Garma [1] discuss the general use of infrared thermography in engineering. However, to effectively identify deficiencies in buildings, it is essential to understand both the thermographic equipment and its operating principles. For the purposes of this study, a Testo 883 thermal imaging camera was used, in accordance with its official user manual [2].

The engineer's expertise and understanding of the camera's functioning, as well as the principles of the infrared spectrum, are of great importance. Equally critical is knowledge of the thermal properties of construction materials [3], such as thermal conductivity and emissivity, which directly affect the accuracy and interpretation of thermographic readings. Šišić et al. [4] highlight the role of thermography in improving energy efficiency in buildings. By combining insights from these sources, infrared thermography can be effectively integrated into civil engineering practice.

This study is based on that foundation and explores the principles of thermography, the visible and infrared spectrum, and the detection of potential structural issues through the use of a thermal imaging camera. A significant number of European and international standards related to thermography [5–7] define the general principles, equipment, and operating procedures. In addition, standards [8–10] provide detailed guidelines for inspection methodologies and report preparation. All thermographic testing presented in this paper was conducted at and around the Faculty of Technical Engineering in Bihać.

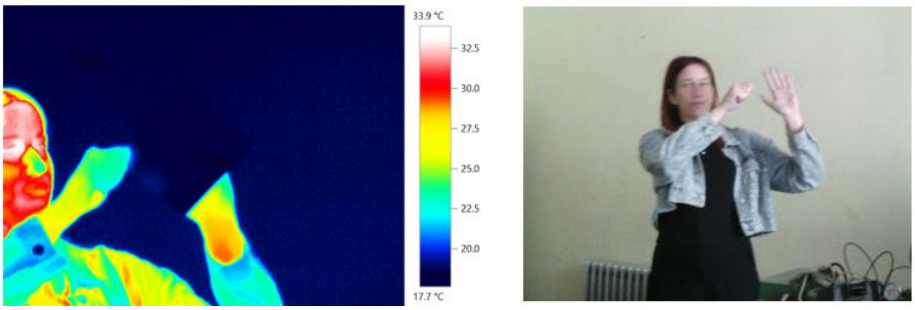
2. General overview of thermography

Thermography is a non-destructive (or non-invasive) method that uses infrared radiation to detect and display temperature differences on the surfaces of various objects, structures, or spaces. All bodies with a temperature above absolute zero emit infrared radiation, and as the temperature increases, so does the intensity of this radiation.

This type of measurement enables remote temperature detection—i.e., temperature measurement without physical contact—unlike traditional thermometers. It also allows for observation in the dark, making it possible to distinguish objects without visible light. Thermography can reveal thermal bridges in buildings, overheating in electrical installations, and hidden moisture. In addition to its use in civil engineering, thermography has significant applications in medicine and the military industry. One of the

key principles of thermography is emissivity. Thermographic cameras detect radiation in the infrared spectrum, and emissivity refers to the ability of a surface or material to emit infrared radiation compared to an ideal black body, which has an emissivity of 1.

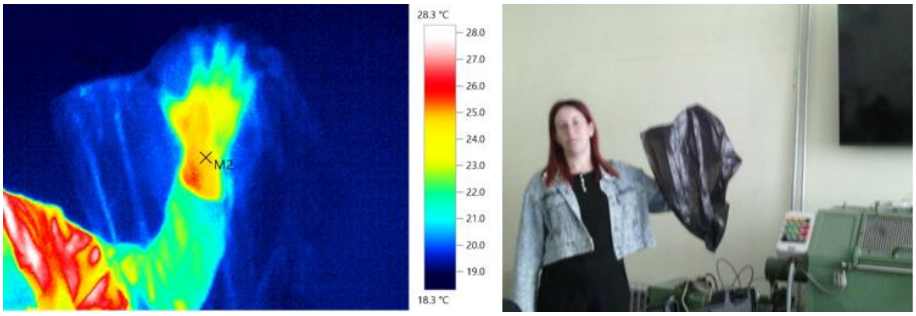
It is important to note that what is visible to the human eye is not necessarily visible in the infrared spectrum—and vice versa. The first example illustrating this concept is shown in Figure 1.



(a) (b)

Figure 1. Glass in the infrared (a) and visible spectrum (b).

Glass is transparent in the visible spectrum. Objects located behind the glass are easily visible to the human eye. This is shown on the right side of Figure 1, where a hand is placed behind the glass. However, when looking at the thermogram, the hand behind the glass is no longer visible because the thermal camera only detects the temperature of the glass surface. Infrared radiation is absorbed and reflected by the glass surface.



(a) (b)

Figure 2. Opaque PVC bag in the infrared (a) and visible spectrum (b).

The next example is a black PVC bag shown in Figure 2. Although it is opaque in the visible spectrum, it is quite visible, or transparent, in the infrared spectrum. The reason for this is that the bag absorbs most of the visible light, making it opaque, but PVC plastic (especially black) is transparent to infrared radiation, which means that heat (infrared radiation) passes through it.

3. Thermography in civil engineering

Thermography is a powerful tool in civil engineering. Its range of applications is very broad. It is useful for detecting heat losses through walls, ceilings and roofs, as well as for identifying moisture and water infiltration, since moisture changes thermal conductivity and is therefore easily noticeable on thermograms. For this study, a Testo 883 thermal camera was used. It is a practical and robust thermal camera designed for non-contact measurement and visualization of surface temperature distribution. It is applied in electrical and mechanical inspections, building inspections, as well as quality control in production.

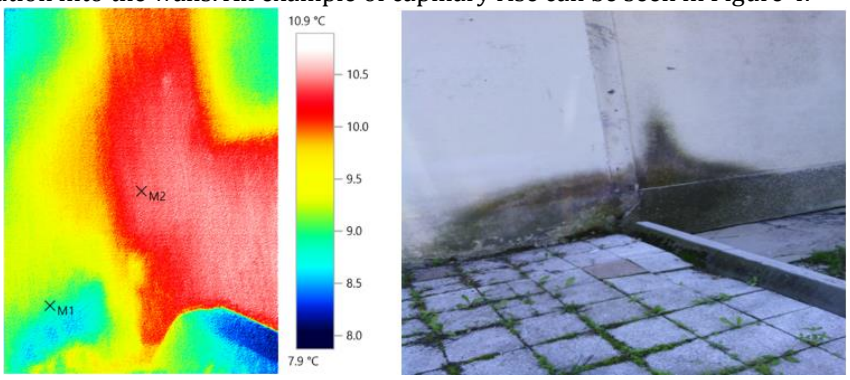
(a) (b)

Figure 3. Thermal Camera Testo 883 (a) and auxiliary equipment (b).

Figure 3 shows the thermal camera that was used to obtain the thermograms.

3.1 Moisture in Buildings

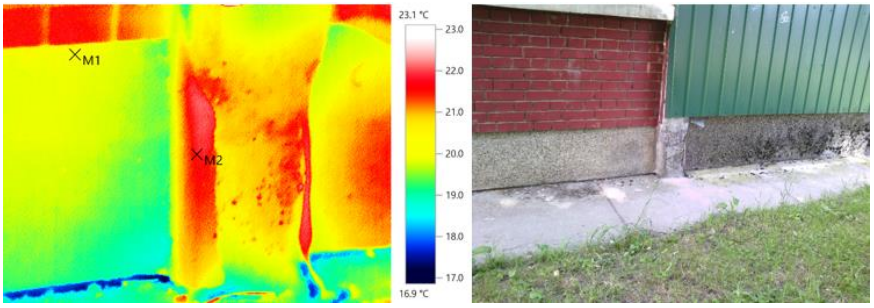
Moisture penetration in a building can occur either through direct water ingress or indirectly through condensation or capillary rise. Negative effects include reduced durability of the structure (such as reinforcement corrosion due to water penetration), delamination of reinforcement layers, possible formation of mold and fungi, as well as the appearance of salts on surfaces caused by capillary water rising from the foundation into the walls. An example of capillary rise can be seen in Figure 4.



(a) (b)

Figure 4. Capillary rise of water through the wall in infrared (a) and visible spectrum (b).

The vertical red surface represents the vertical ring beam. However, around it on the thermogram, a spectrum of different colors—red, yellow, and blue—can be seen, which actually indicate moisture penetration and capillary rise. The same can be observed in Figure 5.



(a) (b)

Figure 5. Capillary rise of water around the vertical ring beam in infrared (a) and visible spectrum (b).

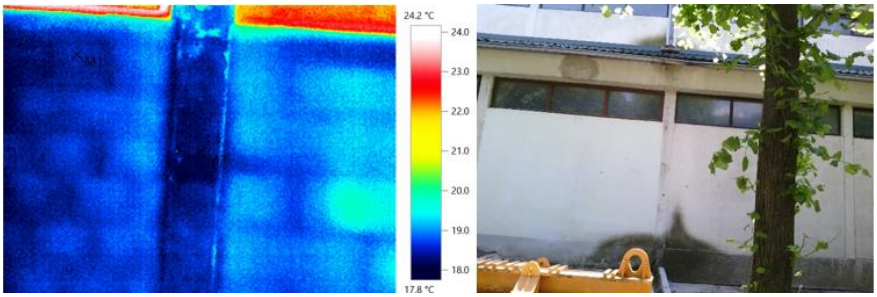
3.2 Wall composition

Different materials have different thermal conductivity and emissivity coefficients. Essentially, this means that a multi-layer wall, such as one made of concrete blocks, facade polystyrene, and facade plaster, does not conduct heat uniformly due to the heterogeneity of its materials. This results in varying temperatures on the thermogram, from which the composition of the wall becomes visible. Examples of materials with their main thermal characteristics are shown in Table 1.

Table 1. Thermal conductivity coefficients and emissivity for materials of a wall.

Material	Thermal conductivity coefficient [W/m·K]	Emissivity
Concrete block	1.4 – 2.1	0.93
Facade polystyrene (EPS)	0.031 – 0.033	0.90 – 0.95
Mineral plaster	0.8 – 1.0	0.93

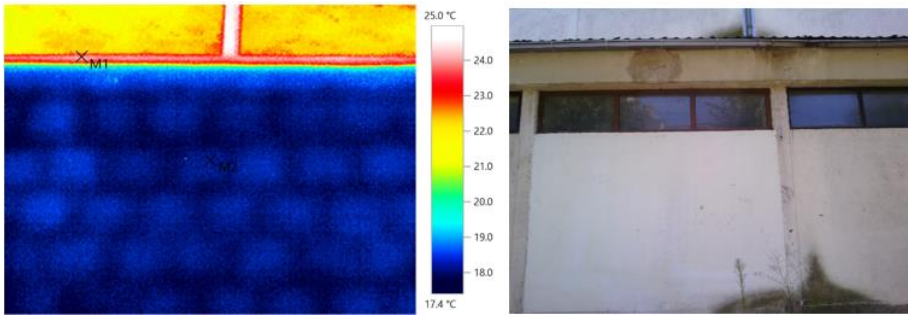
In general, a thermogram can display different temperatures on a surface for various reasons, such as the thickness of the layers, the aforementioned thermal conductivity, thermal inertia, presence of moisture, and damage. The thermal camera shows the surface temperature of the wall, but from this data, it is possible to indirectly infer information about the layers and composition of the wall.



(a) (b)

Figure 6. Visibility of reinforced concrete ring beam and two walls made of different blocks in infrared (a) and visible spectrum (b).

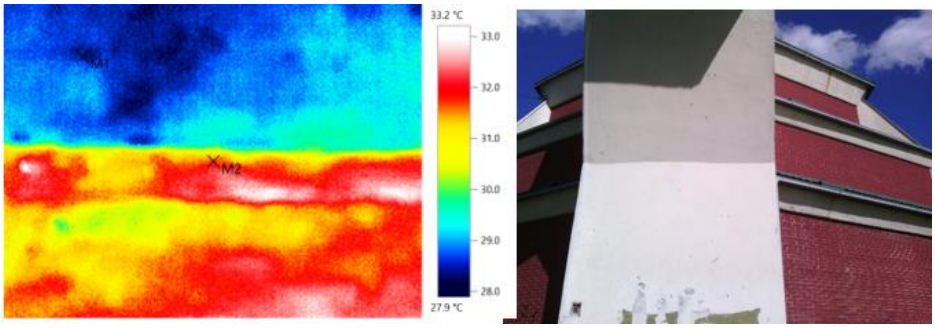
In the thermogram shown in Figure 6, the reinforced concrete ring beam located between two walls can be seen. What is also visible, as a result of the old wall protrusion (left side), is that the right and left sides of the wall consist of blocks of different sizes.



(a) (b)

Figure 7. Thermogram of the new wall (a) and its image in the visible spectrum (b).

Figure 7 shows the thermogram of the new wall, where the blocks that compose it are visible, as well as its image in the visible spectrum, where the blocks cannot be seen.



(a) (b)

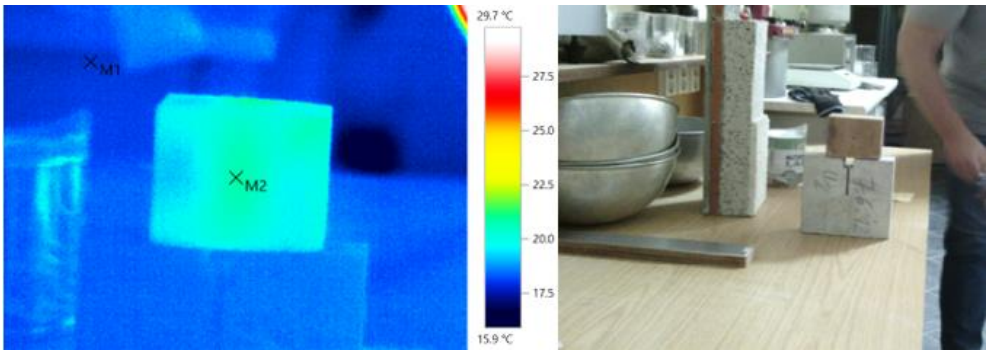
Figure 8. Thermogram of the horizontal ring beam (a) and its image in the visible spectrum (b).

The horizontal ring beam shown in the thermogram can be seen in Figure 8.

3.3 Locating joints in wooden structures

Joints in wooden structures represent areas with different thermal properties. Without additional heating, the temperature differences between the structure and the joints can be very small and difficult to detect using a thermal camera. Therefore, in practice, targeted heating of the surface is applied to create a thermal gradient, enabling clearer identification of the joints. Heating can be natural, i.e., by sunlight, or artificial, using a warm air blower. After this process, the joints respond differently by cooling more slowly compared to the surrounding wood material, which is clearly visible on the thermogram.

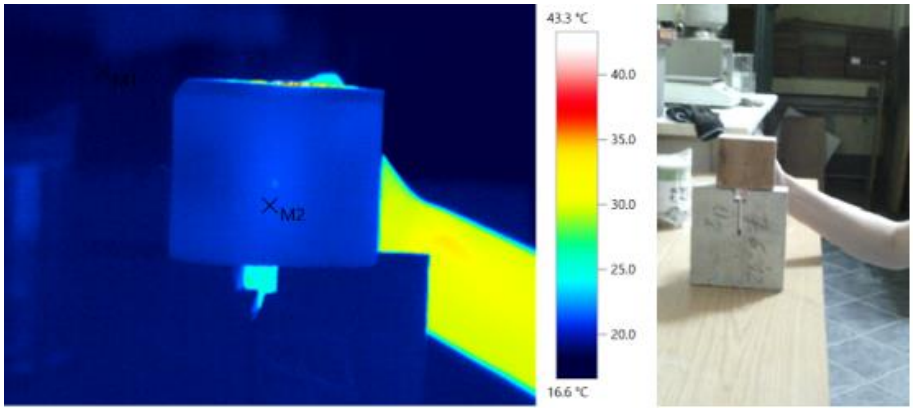
For the first example, a wood sample measuring 8.5 x 8.0 cm in surface area and 4 cm in thickness was used. A screw with a hexagonal head was screwed into the center of the sample. In this case, the screw was heated using a torch, and the heating process was monitored with a thermal camera. Initially, the screw was not visible on the thermal camera.



(a) (b)

Figure 9. Appearance of the sample before heating in infrared (a) and visible spectrum (b).

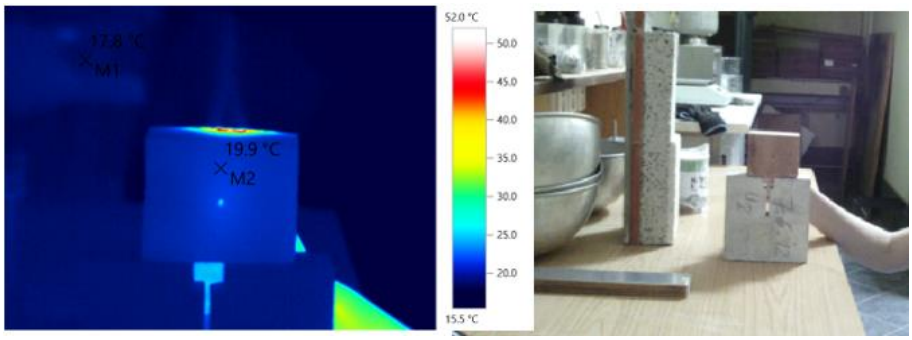
Figure 9 shows the sample in the visible spectrum as well as the thermogram with approximately the same temperature across the entire surface. Heating was then applied.



(a) (b)

Figure 10. Start of heating and visible flame tip of the torch in infrared (a) and visible spectrum (b).

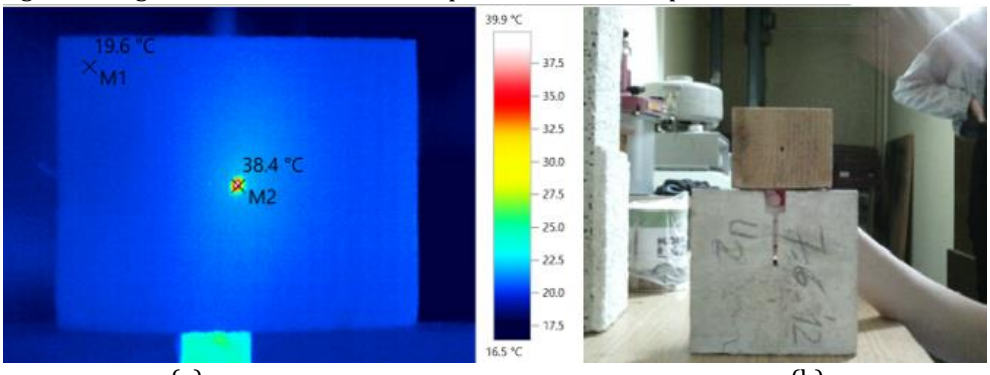
When the heating started, initially only the flame tip was visible to the thermal camera, as shown in Figure 10.



(a) (b)

Figure 11. Start of heat spread on the screw in infrared (a) and visible spectrum (b).

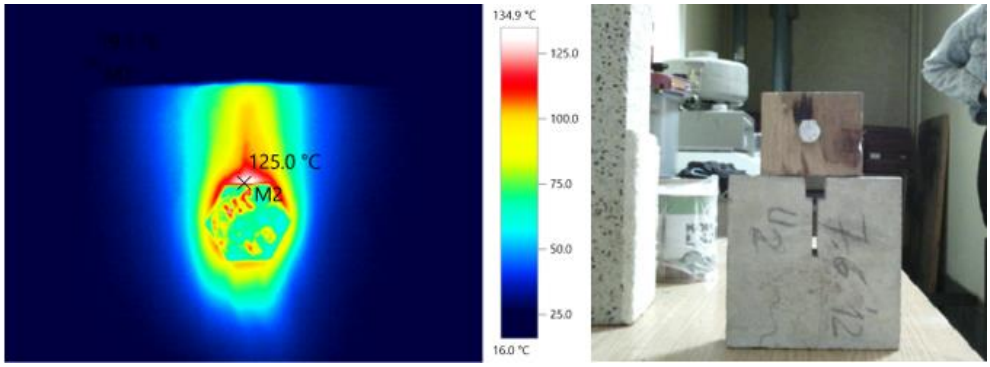
Over the next few seconds, the heat from the flame gradually begins to spread onto the screw, as seen on the thermogram in Figure 11, where the heated spot on the screw expands.



(a) (b)

Figure 12. Heat transfer through the screw and visible enlargement of the hot spot in infrared (a) and visible spectrum (b).

As the heat spread through the screw, the hot spot also expanded, as shown in Figure 12.

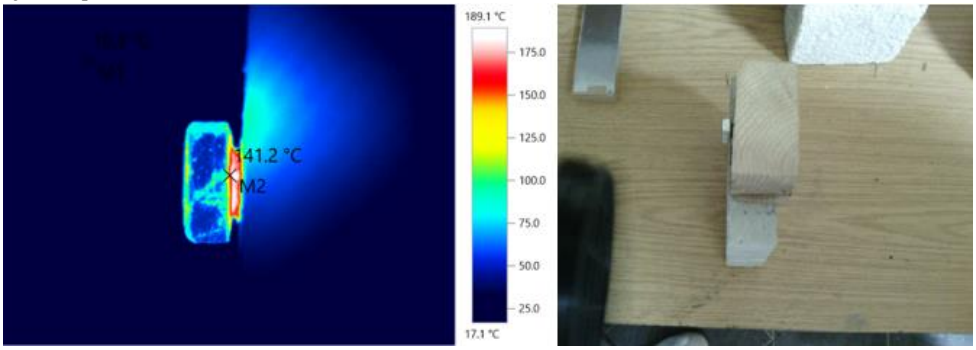


(a) (b)

Figure 13. View of the heated screw from the front side of the sample in infrared (a) and visible spectrum (b).

The total heat transfer occurring through the screw and adjacent materials can be seen in the thermogram in Figure 13.

Screw represents a thermal bridge in a wooden structure. This means it allows increased heat transfer between the warmer and colder sides, because metal (e.g., steel) has a much higher thermal conductivity compared to wood.



(a) (b)

Figure 14. View of the heated screw in infrared (a) and visible spectrum (b).

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For easier understanding, the heat spread from the top side of the screw is also shown. The heat spreading to the surrounding surface of the wooden sample is also noticeable.

4. Conclusion

Thermography in civil engineering represents an important tool and a fast, non-destructive method for analyzing buildings. Thanks to its ability to detect surface temperature differences, thermal cameras help identify many problems that would otherwise remain hidden. When it comes to moisture in buildings, thermography enables the detection of cooler surfaces that indicate increased moisture, even before visible stains and damages appear. In wall composition analysis, thermal cameras facilitate the distinction between different materials based on their emissivity and thermal conductivity. This leads to the identification of insulation and potential thermal bridges. In the analysis of wooden structures, thermography helps precisely locate joints and areas of varying thermal accumulation. This is especially aided by surface heating, which can also help reveal potential weak points in the structure. It is important to emphasize that, for the correct interpretation of data, the operator's knowledge and training are crucial. Understanding the thermal properties of materials, the influence of external factors, and proper calibration of the thermal camera parameters are necessary. Only accurate and precise thermographic analysis enables reliable conclusions and timely action on potential problems within the building. All of this results in increased use of thermography in practice, not only as a diagnostic method but also as a tool to improve energy efficiency

and extend the lifespan of the structure. Infrared thermography should become a standard part of routine inspections of building structures, especially in older buildings or those known to have issues with moisture, insulation, or structural damage. Its regular application allows for the early detection of potential problems, helping to prevent more serious damage and reduce remediation costs. Future research and professional work may focus on quantifying energy losses using thermal imagery and correlating these findings with actual heating and cooling costs. In this way, thermography can also be used as a tool for calculating the return on investment in energy efficiency measures, which has direct applications in the planning of building energy retrofits. Through simulations and experimental testing, it is possible to investigate how layers with different thermal properties—such as thermal conductivity, diffusivity, and emissivity—affect the accuracy of thermal bridge detection using infrared thermography. Future studies could focus on analyzing errors that arise during the interpretation of thermograms of complex wall assemblies. By combining numerical simulations (e.g., the finite element method) with real-world measurements, it is possible to validate heat transfer models and create guidelines for accurate thermogram interpretation in heterogeneous constructions.

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Design and Numerical Modeling of a Gabion Wall in the 'Oaza' Complex, Tuzla

Mirza Memić and Medina Mešić

University of Bihać, Faculty of Technical Engineering, Bosnia and Herzegovina

E-mail: mirza.memic@bih.net.ba

Abstract. As part of the construction of the external landscaping around Building Block B in the residential complex "OAZA" in the Mosnik neighborhood of Tuzla, it was necessary to construct an appropriate retaining structure due to the need for building a service road. A particular challenge was the spatial limitation for forming the cross-section of the roadway, the close proximity of neighboring buildings and a local road, as well as a steep slope. The most rational technical solution proposed was the construction of a retaining structure made of concrete gabions. For the purpose of developing the project documentation and the computational model, detailed geodetic surveys and geotechnical investigations were carried out. Numerical models were created using the Geo 5 software package, which was used to perform the necessary calculations and to provide verification of both internal and external stability. This paper presents the most important phases in the preparation of the project documentation, numerical analyses, and the construction of the concrete gabion retaining structure.

Keywords: slope, gabion wall, numerical modeling

1. Introduction

During the design phase of the exterior landscaping for the residential-commercial building Block B (Lamella B1 and B2) within the "OAZA" residential complex, located in the Mosnik neighborhood of Tuzla, the need arose for the construction of a service road to ensure access and maneuverability of motor vehicles around the building.Due to the limited width of the available space in the immediate vicinity of the structure, it was necessary to extend the terrain. Consequently, the need emerged for the construction of a suitable retaining structure, whose primary function would be to ensure slope stability and enable unobstructed traffic circulation.The complexity of this intervention lies in the challenging geotechnical and spatial conditions, which significantly limited the options for structural solutions. In this context, the construction of a conventional reinforced concrete structure posed a potential risk to slope stability, particularly due to the proximity of existing buildings, narrow working zones, and the specific terrain configuration. As the most rational technical solution, the construction of a retaining structure made of concrete gabions was proposed. This approach proved to be not only technically feasible but also environmentally and aesthetically suitable for the urban setting. The main objective of this paper is to demonstrate the efficiency and practicality of using gabion walls in urban and infrastructure projects, especially in situations where environmental sustainability, ease of construction, and adaptability to terrain conditions are of critical importance.

2. Existing conditions

The existing terrain has a very steep slope, and wooden piles have been installed as a temporary protective measure. In close proximity to the top of the slope, there is a local road and residential buildings. Due to the slope gradient and soil composition, surface erosion has occurred as a result of precipitation, as shown in Figure 1.

Figure 1. Existing conditions around the complex and installed wooden piles – site photographs.

3. Geomechanical properties of the soil

For the purposes of project development and geostatic calculations, a geodetic survey of the existing conditions and a Geotechnical Investigation Report were provided for the construction of the "Oaza" residential-commercial complex. Boreholes B-21, B-22, B-23, and B-24 were taken into account, as shown in Figure 2. No groundwater was recorded in the boreholes. The geomechanical characteristics of the soil are presented in Table 1.

Table 1. Soil stratigraphy according to the geotechnical report. [1]

Description of materials	Layer thickness [m]	Depth [m]
Humus and embankment	0,3	0,3
Yellow-brown clay, hard	2,1 – 2,5	2,4 – 2,8
Yellow-brown sandy clay, medium stiff	0,4 – 0,5	2,8 – 3,3
Brown sandstone, hard	3,8 – 4	6,6 – 7,3
No presence of water was recorded.		

During excavation, the humus layer was removed, and the space between the slope and the retaining structure was backfilled with limestone material.
Based on the analysis of the investigation results, laboratory geomechanical testing of soil samples, comparative experience, and analogies with similar geological environments in the surrounding area, the relevant parameters were adopted for the calculations, as shown in Table 2.

Table 2. Governing parameters of slope layers for geostatic analysis [1].

Layer	Description of materials	φ [°]	c [kN/m^2]	γ [kN/m^3]
Layer 1	Backfill material – Limestone	30	0	18
Layer 2	Stable ground – brown sandstone, hard	27	31	24,6

[a] φ – Angle of internal friction
c – Cohesion
γ – Bulk density

Figure 2. Existing and designed conditions with the location of boreholes B-21, B-22, B-23, B-24 [2].

3. Design solution

Depending on the adopted elements of the roadway, the position, shape, and dimensions of the retaining structure have been defined. The planned roadway has the following characteristics:

- width of 4.5 m + 0.5 m gutter,
- an access platform adjacent to the building of 1.0 m, and
- a berm with a width of 0.55 m.

Considering the conditions under which the retaining structure must be constructed, the most rational solution is the construction of a retaining wall made of concrete gabions filled with stone. Supporting this choice is the fact that any other type of retaining structure would require significantly more time to complete (deeper excavation for foundation works, formwork and reinforcement for a wall 5–6 m high, etc.), whereas gabions can be installed immediately after excavation, which represents a clear advantage in this case.

3.1 Geometry and dimensions of the wall

The adopted retaining wall is a gabion wall. The gabions are concrete with stone filling, measuring 1.0 x 1.0 x 2.0 m. They are installed on a 0.10 m thick MB20 concrete bedding layer. It is mandatory to found the wall on a stable substrate (hard brown sandstone). The gabion wall is a rectangular concrete structure with two internal cells. The wall includes drainage openings (weep holes/barbicans) for water drainage. Their function is to enable unobstructed water flow from the gabion fill, thereby reducing hydrostatic pressure on the wall.

Thanks to its simple assembly and modular design, the elements can be connected in series, allowing the formation of larger structures with continuous drainage and an aesthetically pleasing appearance. Gabion reinforced concrete baskets are manufactured from MB40 concrete with the necessary reinforcement installed.

The total length of the wall is 86.0 m, with a variable height of up to 6.0 m. Excavation is carried out in sections (bays), with their length to be determined during construction according to geomechanical site conditions. For higher parts of the retaining structure (5 to 6 layers of gabions), the maximum bay length is 6.0 m. The cross-section and numerical model of the gabion wall are shown in Figure 3.

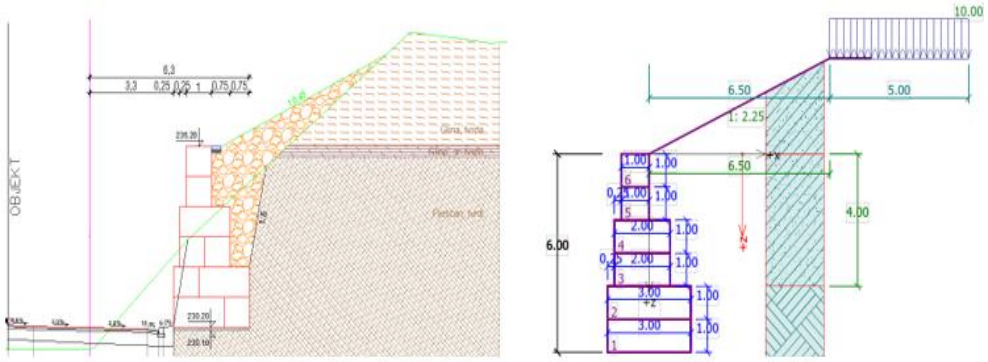

Figure 3. a) Cross-section. b) Numerical model. [2]

Table 3. Governing parameters of gabion materials.

Description of materials	φ [°]	c [kN/m²]	γ [kN/m³]
Gabion – Concrete with fill	40	0	21

[a] φ – Angle of internal friction
c – Cohesion
γ – Bulk density

Table 3 shows the parameters of the gabions.

3.2 Excavation and drainage

If, during excavation, it is determined that the soil composition differs from that described in the geomechanical report or the adopted ground model, and it is established that the bearing stratum is not located in a layer of satisfactory load-bearing capacity, it is necessary to replace the foundation soil. The replacement should be carried out by backfilling coarse stone material in layers up to 30 cm thick, compacted to the required density.

The designed excavation depths for the gabions may be adjusted during construction, provided that the foundation bearing layer of the gabions rests on the substrate. All work execution, assessments, and modifications must be performed exclusively with the consent of the geotechnical supervising authority.

To protect the excavation and the work area, it is necessary to implement a temporary protective base that allows for unobstructed execution of the works, according to the available capabilities of the contractor. Excavation is carried out in bays, and their length will be determined based on geomechanical conditions at the site.

Stormwater drainage from the slope is addressed by installing a concrete channel directly adjacent to the wall, with a total length of 86.0 m. Rainwater from the channels flows into drains and then through HDPE pipes into the newly constructed drainage system. A berm is planned between the wall and the curb.

To adequately collect and discharge stormwater from the roadway, a cross slope of the pavement structure is designed toward the wall (i.e., sloping away from the building), along with the construction of gutters. Water is collected in the gutters, directed into drains, and further to the newly designed drainage system. The uphill side of the slope must be properly arranged and covered with humus soil.

4. Numerical modeling

The geostatic analysis of the gabion wall was performed using the GEO5 software package. The calculations were carried out separately for three, four, five, and six layers of gabions.

The active earth pressure is calculated according to Coulomb's theory, taking into account the wall inclination, slope inclination, and friction between the soil and the wall. The passive earth resistance is calculated using the Caquot-Kerisel method. Seismic earth pressure is evaluated using the Mononobe-Okabe method, which is an extension of Coulomb's theory and includes horizontal and vertical seismic forces.

The earth wedge formed behind the wall is considered skewed, allowing a more realistic representation of pressure distribution, especially on sloped terrain or inclined walls. The allowable eccentricity of the resultant force on the foundation is 1/3 of the foundation width, in accordance with stability criteria (the resultant force must remain within the middle third to prevent overturning).

Verification (stability and bearing capacity checks) is performed according to Eurocode 7 (EN 1997), which includes partial safety factors and different design approaches. Design approach 1 from EN 1997 is used, applying partial factors to reduce actions and characteristic soil parameters [3]. The calculation results for each cross-section of the wall are presented in Table 4.

Table 4. Relevant parameters of the gabion material.

Number of Gabion Rows	Combination 1				Combination 2				Slope stability verification	
	M_{res}	M_{ovr}	H_{res}	H_{act}	M_{res}	M_{ovr}	H_{res}	H_{act}	Combin. 1	Combin. 2
Three	150,39	46,24	116,46	27,42	146,72	52,08	89,36	30,97	Zadovoljava	Zadovoljava
Four	198,99	78,32	131,85	30,25	198,18	95,38	100,32	45,48	Zadovoljava	Zadovoljava
Five	683,25	334,11	248,01	142,89	631,96	348,03	184,05	156,71	Zadovoljava	Zadovoljava
Six	766,96	431,93	264,78	149,03	725,12	468,28	197,40	176,10	Zadovoljava	Zadovoljava

Slope stability is confirmed and satisfactory for all gabion layer configurations.

5. Gabion wall construction in practice

The terrain behind the building needed to be prepared for the installation of the gabions. First, a portion of the slope was excavated, as shown in Figure 4. Then, a base layer of concrete class C16/20 with dimensions of 210 m^2 × 0.1 m was poured, onto which the gabions were placed.

Figure 4. a) Excavation of the terrain. b) Installation of gabions on the base concrete.

The base concrete is installed primarily to stabilize the foundation and to reduce the risk of uneven settlement. Additionally, it acts as a combined footing that evenly distributes the vertical loads from the gabions onto the soil beneath. Furthermore, the base layer helps protect against erosion and washing out of the lower soil layers, thereby contributing to the long-term functionality of the structure. It also allows for precise leveling and shortens the assembly time.

Depending on the slope's position and height, as well as the available space, the gabions were initially installed in layers ranging from two up to six, as shown in Figure 5.

Figure 5. a) Gabion placement procedure. b) Trench excavation.

This section aims to highlight potential problems that can arise during construction. In this particular case, undesirable issues occurred primarily because the contractor, after excavating the trench, neither installed the gabions nor placed a protective base layer, despite clear notes in the project and instructions given by the supervising authority, as shown in Figure 5b.

Following the excavation, there were several days of intense rainfall. Given the steep slope and its height, a smaller surface section of the slope lost stability. Afterward, the contractor installed only a few gabions in an attempt to prevent further soil sliding but did not continue with the construction of the wall for several days.

Figure 6. Temporary retaining structure.

Following such an irresponsible approach to resolving the issue, further soil sliding occurred. The temporary retaining structure, consisting of several gabions as shown in Figure 6, was insufficient to prevent additional slope failure, resulting in significantly greater damage at the site. This also led to unforeseen costs due to the need for remediation of the collapsed slope as well as the road above it. The condition of the terrain after the rainfall and collapse is shown in Figure 7.

Figure 7. Subsidence of the soil and roadway.

After this event, the first step was to repair the caused damage, followed by the continuation of the construction works on the retaining structure, see Figure 8.

After completing the works on the gabion retaining structure, construction of the roadway commenced, and the final appearance around the "Oaza" complex is shown in Figure 9.

Upon completion, the gabion wall presented a naturally aesthetic impression that harmoniously integrates with the surrounding environment of the "Oaza" complex. The wall surface appears rustic and visually appealing, without the need for additional cladding. Thanks to the proper stacking of the gabions, the wall is straight, stable, and free of visible deformations.

Figure 8. Continuation of gabion wall construction.

The entire structure appears compact, functional, and aesthetically suitable for the residential and recreational setting that the "Oaza" complex represents.

Figure 9. Final appearance of the wall and roadway.

6. Conclusion

The paper presents the entire process from the design and numerical modeling of the gabion wall to its construction on site. It is based on realistic geotechnical parameters and modern engineering calculation methods. Based on the results of the stability analyses performed on the numerical models, it has been demonstrated that the proposed structure meets all requirements for both internal and external stability.

The use of gabions has achieved not only structural stability but also excellent drainage and aesthetic integration into the environment.

This paper highlights the necessity of responsible execution of works. It emphasizes that we must not underestimate the power of nature and human negligence, which led to unforeseen circumstances and additional costs. Although this complicated and prolonged the construction time, it ultimately did not prevent the wall's functionality in protecting the roadway and the complex itself.

The wall's execution on site definitely verifies the practical applicability of the performed calculations, while the final appearance further contributes to the overall visual impression. This project serves as an example that gabion systems represent a sustainable, economical, and effective solution for slope stabilization in urban areas and can thus serve as a model for similar projects in the future.

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Architectural and energy reconstruction of a family houses

Aida Husetić and Azra Avdagić

University of Bihać, Faculty of Technical Engineering, Bosnia and Herzegovina

Email: ahusetic@gmail.com

Abstract. The paper deals with the architectural and energetic adaptation and reconstruction of a family residential house in Bihać. It will explain the constructive reconstruction and the procedures for replacing the existing structural elements with new ones, as well as the reuse of the existing, usable, parts of the building. Energy rehabilitation included the creation of a completely new facade envelope of the building, the replacement of external and internal windows and doors, as well as the replacement of outdated thermo technical systems and their adaptation to the conditions of energy-efficient renovation of the building. The reconstruction also included the architecturally functional reorientation of the space, and the replacement of all installations in the building to achieve low-energy and smart standards in construction.

Keywords:
Building reconstruction, Energy efficiency, Family house

1. Introduction

The reconstruction of the family house was carried out in 2024 and included a complete structural reconstruction, as well as the removal of existing elements of plumbing, electrical and heating installations and the installation of new ones.

The project included a family house built in the 1980s, and a garage facility built somewhat later.

Given that the house was not completed during the original construction process, the attic was built at the level of rough construction works, and that the facility was damaged in wartime and no serious damage repair was made, it was necessary to perform a static inspection of the facility, record the current state of the functional organization of the space, analyze the constructed elements of the floors, wall coverings, roof structure, facade envelope, and the installation systems in the facility.

According to the investor's idea, the facility was to be reconstructed at a functional level in order to adapt to the requirements of a family of four with an emphasis on common areas, while the requirements regarding thermo technical systems were minimal, i.e. the decision was made by the architect.

The reconstruction and adaptation of the residential building, and the construction of auxiliary facilities in the yard, lasted approximately a year and included design work, coordination of the project with the investor, demolition and removal of parts of the building, and construction.

2.The existing condition of the house and surroundings

The family house is located in a residential area. The surroundings consist of family residential buildings of the same height and similar dimensions of the building. A building line has been established in the area. The building is in a courtyard, where there is also a garage. The dimensions of the building are 10.37 x 12.28 m in the ground floor, or 10.37 m x 11.32 m. The house is built on three residential floors, ground floor, first floor and attic.

In terms of function, the ground floor is intended for the living room, while the upper floors are planned for bedrooms and rest rooms.

The entrance part of the building is located centrally, along the axis of the space and from it there is access to the living room, kitchen and dining room and bathroom. In the central part there is a staircase that connects the floors of the house. The space organization is very similar on the floors, where the bedrooms and bathroom are accessed from the central landing. It is about the traditional architectural organization of space, characteristic of the 80s of the last century in residential construction in these areas.

Figure 1. House before reconstruction.

In the architectural-aesthetic, i.e. design sense, the building had no significant expressive elements, on the contrary, it looked quite unsightly. When it comes to the construction elements of the building, the found condition of the structural elements was found to be partly satisfactory - all elements of the construction of the walls and stairs met the basic criteria, while parts of the roof structure showed significant damage and structural deformations.

The floors in the entire building are made without the mandatory layers of thermal insulation and waterproofing. This was especially probleatic in the ground-floor part of the building, where due to an incorrectly constructed floor structure, the floor was damaged by moisture and capillary water that penetrated parts of the walls.

In the attic part of the house, the floor structures were not constructed, the final layer was a reinforced concrete slab.

The 25.0 cm thick brick block walls were plastered with lime mortar in a layer thickness of 2 cm, which was damaged, damp in parts, partly due to leaking roof construction, partly due to capillary moisture. All floor coverings, parquet and ceramic tiles suffered significant damage and were worn out.

The exterior windows and doors were wooden, glazed only partially with insulating glass, and mostly with double glazing with thermal bridges. The facade of the building was also in poor condition, without a thermal insulation layer, or rather made as a cement mortar plastered wall. All the interior dooors was also wooden, damaged or worn out, the doors made as double-ply cardboard honeycomb, providing neither thermal nor sound insulation between the rooms.

The overall condition of the building elements of the house can be characterized as unsatisfactory in terms of modern requirements for the construction treatment of individual building parts and a building as a whole.

The garage building, although of recent date, proved to be structurally unstable, due to the lack of a foundation structure and a poorly executed reinforced concrete slab, 8.0 cm thick. The first inspection showed deflection in the slab and wooden eams as part of the roof structure. [1]

2. Reconstruction concept

The project includes a complete architectural and structual reconstruction of the residential building in the existing dimensions, as well as the construction of an auxiliary building next to the pool in the yard.

The analysis of the available space on the location showed that the maximum dimensions of the auxiliary building, garage and gazeebo, can be 5.40x 18.00 m. Considering the purpose, the building was designed with the following contents; garage area where the elements of the heating installation are located, area for pool equipment, sauna, sanitary facilities, and a lounge with a small kitchen.

The pool has a maximum dimensions of 4.0 x 8.00 m and is located in the back yard next to the yard fence. The free space next to the pool in the extension of the gazebo is approx. 5.70 m wide. Given the small size of the yard, access to the pool, or gazebo, is from the building, while access to the garage is from the street.

Figure 2. Condition of the building, before reconstruction - floor plan of the ground floor and details of the interior [1].

Architectural reconstruction icludes a complete functional change of the building parts in accordance with the variant solutions that were previously made, as well as the investor's suggestions regarding the second floor/attic regarding the organization of bedrooms and bathrooms.

This solution includes three residential floors with the following content: ground floor (entrance area, living room, kitchen and dining room, pantry or laundry room), first floor (bedrooms, master suite with sleeping area, bathroom and dressing room), terrace with master suite and shared bathroom, second floor in place of the existing attic with lounge area and bedroom and bathroom.

The reconstruction included works on the demolition and dismantling of all floor and wall coverings, partition walls, dismantling of complete interior and exterior doors and windows, complete dismantling of the roof covering and wooden roof structure, and dismantling of all sewage and water distribution and pipe installations.

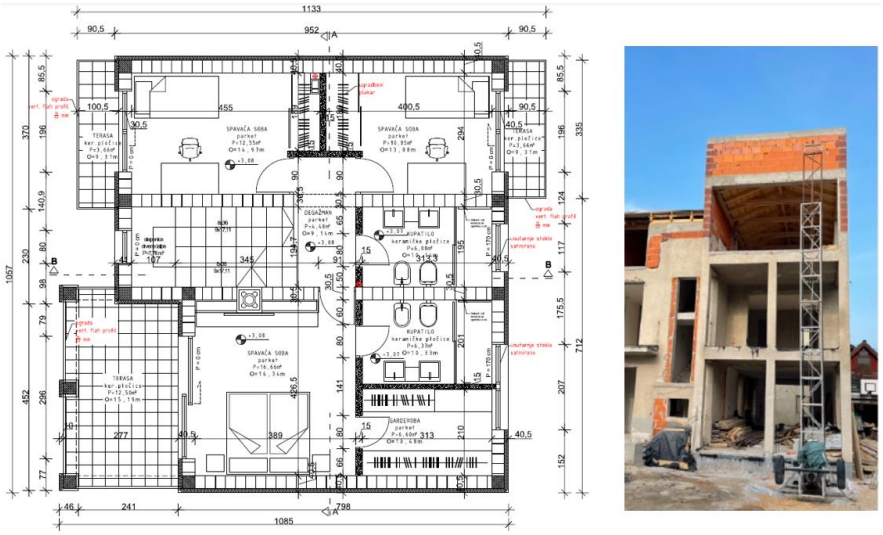


Figure 3. Condition of the house, after reconstruction -the ground floor plan and detail during the reconstruction [1].

Given the reconstruction concept, it was necessary to create a completely new roof structure using a ventilated roof system, in accordance with the requirements for achieving low-energy house standards. New walls were built to increase the height of the existing attic and achieve a higher floor height. Complete waterproofing of the ground floor part of the building was carried out, after which a new reinforced concrete slab was poured, anchored to the existing foundations and walls. New partition surfaces were built in accordance with the new functional organization of the space, new heating installations, electrical installations and plumbing installations. In addition to completely new floating floors, completely new ceiling coverings made of gypsum cardboard and gypsum cement boards were made. Finally, a completely

new ventilated facade was created on one part of the building with a facade cladding made of aluminum composite panels and external aluminum windows with a three-layer glass infill was installed (on large surfaces the glass is triple-layer VSG glass).

The composite panel consists of a plasticized aluminum sheet, a non-flammable FR core and a lacquered aluminum sheet on the back. The substructure for this plate is steel galvanized profiles that are bolted to the wall of the building.

2.1 Energy reconstruction

Energy reconstruction in this case implied a complete reconstruction of the building's outer envelope:

- replacement of all exterior doors and windows (existing was wooden and worn out, with glass layer of a 4 mm, without thermal insulation layer between the glass panes),
- new layer of thermal insulation material on all external walls of the building, under the new foundation slab and as part of the roof structure,
- creation of new floating floors on existing reinforced concrete slabs,
- new heating and cooling system for the building construction.

During the architectural and HVAC design phase, a calculation of the annual energy needs of the existing building was made to determine the condition before the reconstruction, and a comparison was made after the energy reconstruction was completed.

Figure 4. shows the energy certificate of the building's construction parts before the reconstruction, which shows that the building's annual energy needs for heating are 273.49% [2].

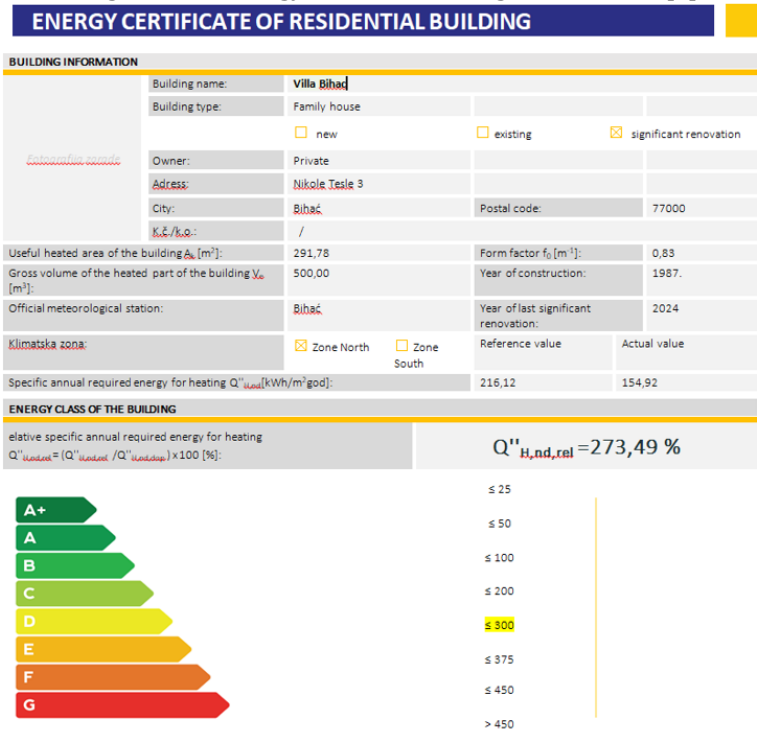


Figure 4. Energy certificate of the building before reconstruction.

The input data for the calculation in the KI expert BiH software package were as follows:

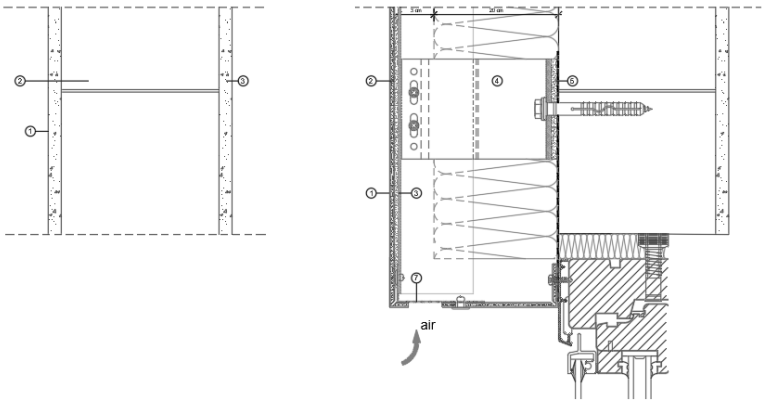
- floor area on the ground, A=116.29 m2
- floor area towards the attic, A=84.30 m2
- area of external walls, A=375.47 m2
- roof area, A=103.16 m2.

The calculation before the reconstruction showed the following results of the coefficient U (W/m2K) as relevant data, based on which it is possible to estimate heat losses in the building [2]:

- windows and balcony doors – 2.50-3.50,
- floor on the ground – 2.50,

- floor on the first floor – 2.42,
- external wall – 1.54,
- pitched roof -0.80 [2].

The basic principle of increasing the energy characteristics of a building is the thermal insulation of the external wall, i.e. walls towards the unheated space. In this case, two types of facade thermal insulation were applied, expanded polystyrene on part of the building and rock wool on the other part of the facade, where the facade was made as ventilated, with a cladding of composite aluminum panels. The layers of the external facade wall on the part of the ventilated facade before and after reconstruction are shown in Figure 5.



1 - cement plaster 2 cm
2 - brick block 25 cm
3 - cement plaster 2 cm

1 - REYNOBOND cladding
2 - adhesive system
3 - vertical T / L - profile
4 - MacFOX - support bracket
5 - Insulator 20cm
7 - hole profile

Figure 5. Layers of the outer wall before and after reconstruction [3].

When implementing the thermal insulation layer on the outside of the wall, two solutions were applied for the final layer that protects the thermal insulation layer and the rest of the wall from external atmospheric influences. The first solution is characterized by the implementation of the external protective layer by full-surface bonding to the thermal insulation layer (compact facade).

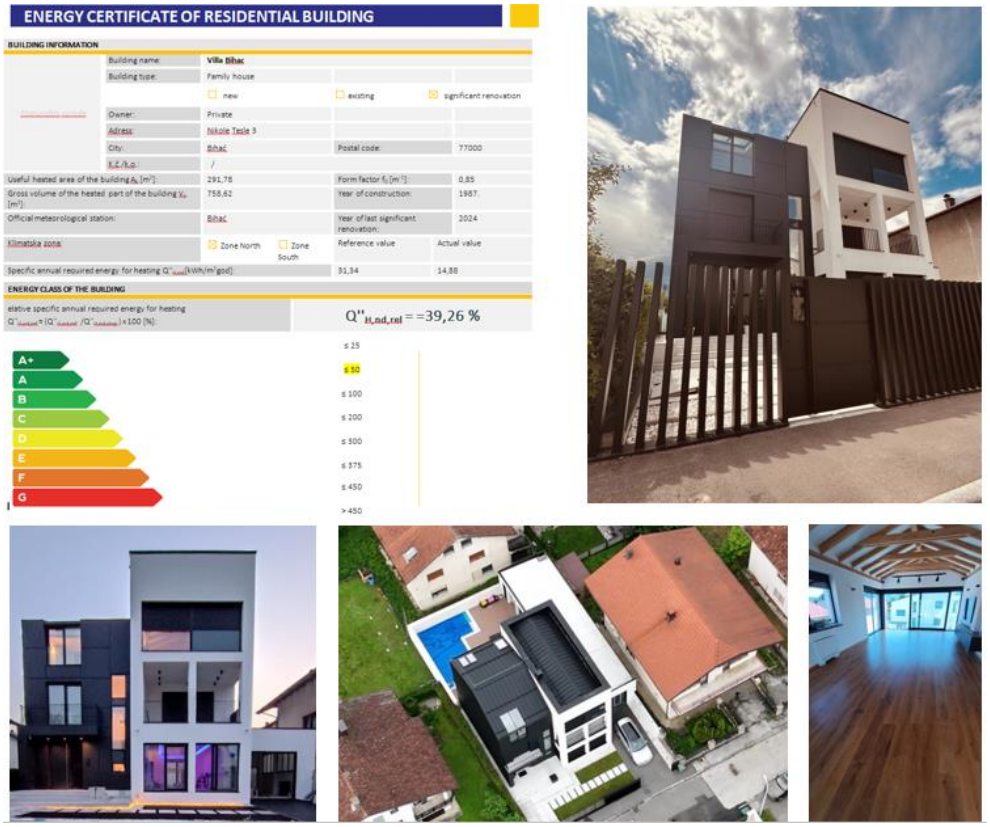


Figure 6. Energy certificate and photos of the building after reconstruction.

In the second part of the facade, the layer is in the form of individual elements fixed to the appropriate substructure, so that between the protective coating and the thermal insulation layer there remains a layer of air that is ventilated to the outside (ventilated facade). The calculation after the reconstruction showed the following results of the coefficient U (W/m2K) as relevant data, based on which it is possible to estimate heat losses in the building [2]:

- floor on the ground – 0.21,
- floor on the first floor – 0.22
- external wall – 0.14
- pitched roof -0.20-0.21. [2]

The thickness of the thermal insulation on the pitched roof is 20 cm. The insulation is placed in two layers; one layer between the rafters and one layer above the rafters, in order to prevent the occurrence of thermal bridges. Great care was taken to prevent the occurrence of point thermal bridges at the contact of the steel facade substructure with the outer wall, where a thin layer of glass foil is placed under the profile.

After the reconstruction, a calculation of the energy required for heating was made calculate annual energy needs of the building for heating are 39.26%, which showed that the investment is profitable many times over. The energy consumption for heating in the reconstructed building is almost 7 times lower.

3. Conslusion

The approach to architectural renovation and reconstruction of buildings is today inseparable from energy efficiency as an imperative in the construction of new buildings. All measures taken in the building to consume less energy for heating, cooling, hot water preparation, lighting, etc. are listed above. These

measures are called energy efficiency measures of the building and include all phases of the building construction, from design through construction and craft works, to measures taken during the exploitation of the building.

Energy efficiency should not be equated with energy saving because that would imply certain sacrifices, the point here is in the better quality of life in the space achieved by the implemented measures.

This paper emphasizes architectural and construction measures to improve the energy characteristics of the building, with a brief review of new technological solutions for HVAC systems.

This paper provides a brief overview of the architectural and construction measures for the reconstruction of the building, which also include energy efficiency measures. The entire process lasted a year and a half and included design, calculations, and supervision of all phases of construction and building equipment instalation.

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The N2 method for seismic analysis of structures

Majudin Muratović[1] and Jasmina Hadžajlić[2]

[1] "Džemal Bijedić" University, Mostar, Bosnia and Herzegovina
[2] "Interprojekt d.o.o. Mostar, Bosnia and Herzegovina

E-mail: majudin.muratovic@unmo.ba

Abstract. For the numerical analysis of structural models under seismic loading, various methods are used. If we are interested in the time history response of the structure, the direct integration method is applied. When designing, if we only need the maximum values, they can be calculated with appropriate accuracy using response spectra and modal analysis. In regulations and practice, the equivalent static force method is most used, as it is simple and applicable only to regular and symmetrical structures. The actual response of structures, which sustain damage during an earthquake, can be realistically simulated only through nonlinear analysis. To monitor the response of a structure in the nonlinear domain under earthquake conditions, nonlinear dynamic and static seismic analyses have been developed. Due to the complexity of nonlinear dynamic analysis, nonlinear static seismic analysis has been developed over the past two decades, which can generally be classified into conventional and adaptive approaches. This analysis is used to assess the system's response to earthquake action, indicating the locations of critical points where significant nonlinear deformations can be expected, as well as the global response of the structure in the nonlinear domain.

1. Fundamentals of the nonlinear static N2 method

The procedures used today for seismic design are mostly based on elastic models. [1] This represents a traditional approach in seismic calculations of structures, which is based on satisfying fundamental requirements by verifying the limit state of load-bearing capacity and the limit state of usability through elastic structural calculations. To avoid nonlinear calculations of structures, the energy dissipation capacity of the structure is considered by performing a linear calculation based on reduced elastic response spectra of ground acceleration. The reduction is carried out using the response factor q, and the thus reduced elastic spectra are called design spectra. However, there are shortcomings of such an approach, which are as follows: [2]

- The recommended values for the response factor are approximate and do not necessarily represent a specific structure.
- When the structure's response enters the nonlinear domain, force redistribution and deformations occur, which are not accounted for in the calculations.
- The failure mechanism cannot be predicted by elastic force and deformation distribution.
- The distribution and values of deformations in the inelastic domain bear no resemblance to those in the elastic domain.

Thus, it should be noted that the application of an empirical factor does not accurately reflect the actual response of the structure, especially when dealing with a new or irregular structural system. Therefore, it is now widely agreed that the existing methodology, deeply rooted in seismic regulations, needs to be changed. Procedures should be developed to appropriately assess the requirements in terms of stiffness, strength, and ductility of the structure, as well as its energy dissipation capacity. Secondly, these procedures should not be more complex than necessary while considering the uncertainty of input data. The methods

used in seismic regulations are mainly based on the assumption of linear-elastic structural response and cannot meet the first requirement. On the other hand, nonlinear dynamic calculations using time-history analysis performed with multi-degree-of-freedom mathematical models are not practical for everyday work. In the short term, the most suitable approach appears to be a combination of nonlinear calculation and response spectrum-based approaches. Examples of such an approach can already be seen in American regulations. Scientific research efforts by a group of researchers from the Institute for Structural Engineering, Earthquake Engineering, and Construction Informatics align with these tendencies.

As a result of extremely high material damage caused by earthquakes, Japan has established the belief that existing methodologies for building design in seismic zones need to be supplemented. The primary goal is always to prevent collapse and thus protect human lives. Additionally, damage should be limited within planned frameworks, requiring greater attention to damage control. This led to the development of the so-called performance-based design. The goal of this method is to design structures that are controlled and have predictable response under earthquakes of various frequencies. [1]

The displacement-based approach proves to be a much better choice in striving for a more realistic understanding of seismic effects than the traditional force-based approach. The goal of modern codes and standards for structural calculations in seismic regions is to ensure sufficient energy dissipation capacity without significant reductions in local and global load-bearing capacity under horizontal and vertical loads and without damage that would limit the usability of the building. The most accurate description of the problem is undoubtedly provided by nonlinear seismic analysis using time-history acceleration records, which, in the long term, is the correct developmental path and ultimate goal. However, due to its complexity and demands, it is still beyond the scope of practical application. Between linear methods and nonlinear dynamic calculations using time-history acceleration records, the nonlinear static approach serves as an intermediary and currently the most rational sustainable solution. [2]

For about twenty years, research has focused on developing procedures to assess seismic response to achieve a satisfactory balance between required reliability and applicability in everyday design. In 1987, the first version of the procedure was published. The procedure was named the "N2 method," where N represents nonlinear calculations, while the number 2 signifies two mathematical models (MDOF system and SDOF system). Since 1987, the method has gradually evolved to its current version. The most important works related directly or indirectly to the development of this model were published in the publication "Towards a New Methodology for Seismic Design of Buildings." It should be noted that, like all approximate methods, the N2 method is used only within a limited scope of application.

Earthquake loading, depending on its intensity, causes parts of the load-bearing system to enter the nonlinear material response domain. Therefore, it is crucial for engineers to predict the response of the structure once its individual elements exceed the limit of linear-elastic response. For this purpose, the pushover analysis method was developed. This method represents a nonlinear static analysis of a selected structural model subjected to realistic vertical loads and horizontal loads consisting of a series of lateral forces applied at the floor levels. The distribution of horizontal forces along the height is chosen to approximately match the structure's first mode shape. The process continues until the complete degradation of the load-bearing system, structural instability, or predefined limits (usually expressed in terms of maximum displacement) are reached. It can be observed that as structural elements yield, the slope of the capacity curve gradually decreases. In other words, the tangential stiffness deep in the nonlinear domain can drop to only a few percent of its initial elastic stiffness. A simpler form of pushover analysis involves applying a series of lateral forces at floor levels proportional to the first mode shape, with the force intensity gradually increasing.

The principle of the method is to monitor the system's response to increasing lateral force while maintaining constant vertical loads. From the obtained relationship between lateral force and reference displacement, the earthquake resistance of the system can be determined. [3] The pushover method is essentially a modern version of the classical ultimate strength calculation. The nonlinear static N2 method for determining the target displacement of a structure subjected to seismic actions combines the pushover analysis of a multi-degree-of-freedom (MDOF) model with spectral analysis of an equivalent single-degree-of-freedom (SDOF) system. In this way, the method compares the seismic capacity of the structure with the

seismic demand expressed by the response spectrum, which is typically provided for single-degree-of-freedom systems. [4]

Further improvement of the procedure would involve redefining the model after each stiffness change, i.e., after an element reaches its yield limit. This means recalculating a new fundamental period of vibration (somewhat longer), the corresponding fundamental mode shape, and a new distribution of horizontal forces. This would expand the scope of calculations compared to simpler forms of nonlinear static analysis, which, when implemented in certain computational programs, can be performed in a single pass. **[3]**

2. The application of the nonlinear method.

The nonlinear seismic method is used to assess the response of existing structures, as an alternative to linear-elastic analysis that uses the response factor q to estimate the expected plastic mechanism and damage distribution, as well as to verify reinforcement values.

The currently available version of the N2 method is only applied for the assessment of seismic response of planar, i.e., symmetric structures. Current research is focused on expanding the method to cover three-dimensional (asymmetric) buildings and irregular bridges. A simplified method for the calculation of incremental pushing for asymmetric buildings has been developed by extending the so-called three-dimensional method into the nonlinear domain. Significant tests of dynamic response of asymmetric single-story and multi-story buildings have been conducted. In recent years, the scope of the method has expanded to include bridges and frame buildings with infill. [1]

In general, the results of the N2 method are acceptably accurate if the structure oscillates predominantly in its first mode. This is a significant limitation, restricting the types of structures for which the N2 method is applicable. Research is ongoing, after which the N2 method will be expanded to consider the effects of higher modes on structural response during earthquakes.

In order for nonlinear analysis to be applicable, the cross-sections and reinforcement quantities must be assumed beforehand, and the result will provide deformations (displacements and relative displacements), i.e., damage to the structure (plasticization of certain cross-sections), while in linear methods, reinforcement is obtained as the final result.

Although the procedures on which the nonlinear static method is based have been known for a long time, they are applied in practice only with the introduction of the AD format. This is the format introduced by Freeman in 1998, where acceleration is on the vertical axis and displacement is on the horizontal axis, which also allows for the visual representation of the process.

The procedure is applied to deformable objects with ductile load-bearing elements. Deformable structural elements are, by definition, those elements that exhibit stable response in the nonlinear domain under cyclic loading. Brittle (non-ductile) failure mechanisms must not occur in any of the primary load-bearing elements. Although this calculation method can be applied to all structures, its most common application is the assessment of existing buildings for horizontal seismic forces.

By comparing the deformability of the structure with the required degree of deformability under the influence of standardized seismic forces, it is possible to determine the safety of the object in relation to the earthquake. When conducting the analysis, it is allowed to apply the nonlinear model, assuming bilinear: linear-elastic, ideally plastic response for individual structural elements.

The method is included in the proposal for the European standard Eurocode 8. The N2 method is applicable both for the design of new structures and for assessing the response of existing objects. Since the method is nonlinear, all-important characteristics of the structure should be considered before starting the calculation.

3. Analysis of reinforced concrete frame structure using the Pushover method in the SAP2000 software package.

A four-story reinforced concrete frame structure was analysed for seismic loading. The selected structure has simple and regular dimensions in length, width, and height, thus meeting the requirements for regularity. [5]

The symmetry of the building creates a favourable situation for the earthquake analysis, reducing the difference between the centre of mass and the centre of stiffness. Additionally, a uniform distribution of stresses is achieved on the elements that bear the seismic forces. The frame has a story height of h=3,00 m, with three equal spans in orthogonal directions, dimensions of l = 4.00 m. the dimensions of the cross-sections of the columns are 35/35 cm, and the beam 35/40 cm. The thickness of the slab is 20,00 cm.

The structure is subjected to constant and variable loads. The self-weight of the frame is considered by the SAP2000v16 software package. In addition to the self-weight, the permanent load includes the load on the slabs 2,00 kN/m^2. The variable load is 1,50 kN/m^2 of the the slabs.

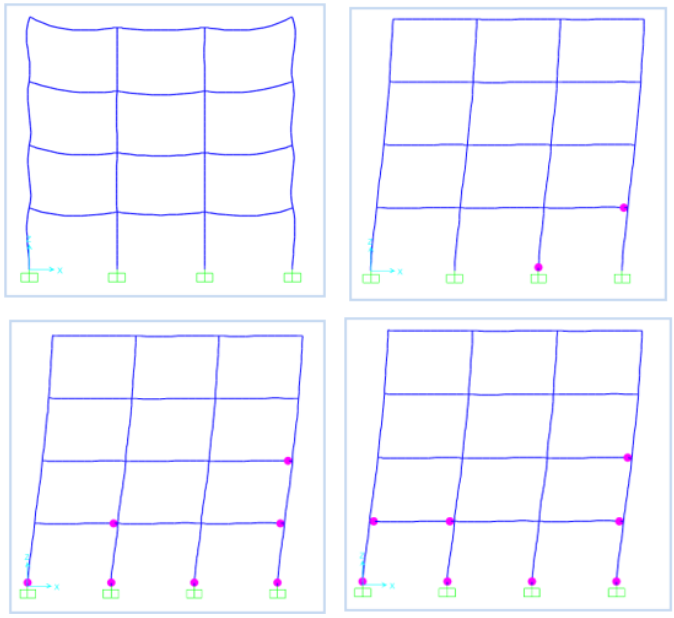

Figure 1. Formation of plastic hinges from step 0 to step 11 (steps 1, 9, 10, and 11)

The observed structure is located in the XIII area of MKS-64, so according to EC8, table 1, subsection 2.1.1., this area corresponds to a design ground acceleration of 0,20g. According to EC8, a foundation on soil category A, which represents rock or another geological formation, including at least 5,00 m weaker material at the surface, has been selected. The importance class of the building II, γ = 1,00. the value of the viscous damping is taken as ξ = 5%.

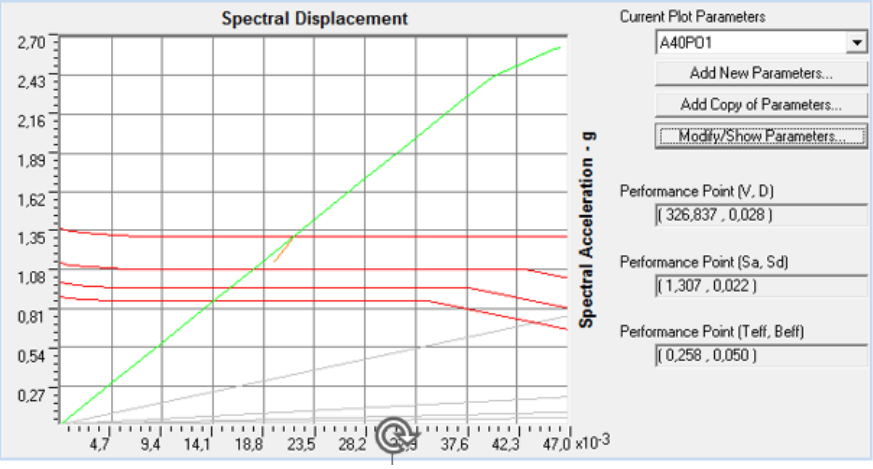

Figure 2. Capacity spectrum for a design ground acceleration of 0.20g, amplification factor 100

It is estimated that the structure can withstand 185 cycles within its elastic deformation capacity and 20 cycles within the inelastic deformation range.

4. Conclusion

The nonlinear static seismic N2 method provides engineers with the ability to plan and control the behavior of a structure in the event of seismic forces. In this way, it is possible to predict the locations where plastic hinges will initially form, i.e., places where some of the energy will be dissipated. This concept, the concept of programmed behavior, provides insight into the system's behavior during the development of nonlinear deformations and the control of pre-selected failure mechanisms.

In the example of a reinforced concrete frame structure analyzed using the pushover method, and the results obtained, it is evident that the ingrained assumption about seismic calculations, which suggests large internal forces, is not valid. The required amount of reinforcement for the structural elements mainly depends on the bending moments. Therefore, larger amounts of reinforcement steel do not need to be installed in such a structure, as was always considered necessary.

Of course, it is important to keep in mind the limitations and drawbacks of such a method, among which the planar analysis of the structure and the predominant oscillation of the structure in the first mode of oscillation stand out.

If we model the structure exactly as contemporary rules and standards require, it will be sufficiently safe to withstand the anticipated seismic load. Moreover, the economic aspects of construction will also be satisfied. This approach to modeling the structure, with predefined locations for energy dissipation, has been receiving increasing attention in recent research. Modern methods of structural analysis, supported by advanced computational programs and the rigor of contemporary standards, aim for a better understanding of the structure's behavior, thus leading to more resilient buildings to seismic loads.

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Types of glass and application in architecture and construction – A review

Ilhana Sinanović[1] and Sanin Džidić[2]

[1]International BURCH University Sarajevo, Faculty of Engineering, Natural and Medical Sciences, Sarajevo, Bosnia and Herzegovina
[2] University of Bihać, Faculty of Technical Engineering, Bosnia and Herzegovina

E-mail: ilhana.sinanovic@stu.ibu.edu.ba

Abstract. Glass is an essential material in modern construction and design, offering aesthetic, functional, and structural benefits. This paper explores various types of glass and their applications, emphasizing their suitability for different architectural and engineering needs. From basic float and annealed glass to advanced tempered, laminated, and fire-rated variants, each type serves distinct purposes. Insulated and low-emissivity (Low-E) glass enhance energy efficiency, while wired and fire-rated glass contribute to safety in fire-prone structures. Understanding the unique properties and the strategic selection of these glass types helps architects and engineers ensure structural integrity, safety, and compliance with modern sustainability and design standards.

1. Introduction

Glass is one of the oldest and most widespread materials that is indispensable in almost every aspect of human lives, starting from architecture and civil engineering, industry (car, kitchen assemblies) and scientific laboratories. Glass is a non-crystalline, rigid, fragile material that is either transparent or translucent. It is a supercooled liquid with extremely high viscosity and no distinct melting point. Glass is produced by melting a combination of various metallic silicates or borates, typically including compounds of sodium, potassium, calcium, and lead [1]. It is the only material that can be described by two antonyms - it is both fragile and strong. Its unique properties, such as transparency, chemical stability and resistance to corrosion, make it useful in different applications.

Glass is actually non-combustible: it does not burn nor provides combustion, but when it is exposed to high temperatures or flame, there are thermal reactions that can cause cracking, deformation or melting, depending on type and conditions it is exposed to.

The presence and usage of glass in everyday life is so common that people rarely notice the existence of such material. The existence of glass reaches into ancient times, when most of the glass used back then was found in nature. Since it was easy to form it, there is no wonder that people actually wanted to start the production of glass.

In layman's terms, glass is actually melted and chemically transformed sand. In order to make sand melt, it is necessary to heat it up to approximately 2300 °C. Sand is comprised of small grains of quartz crystals made up of silicon dioxide (silica). On a molecular level, heated sand loses its crystalline structure and gains some new, somewhere in between solid and liquid structure – an amorphous solid state.

Even though, silica (SiO_2) which gives glass transparency and strength, is most important material in glass production, in order to make glass durable and workable other materials, such as soda ash (sodium carbonate, Na_2CO_3), limestone (calcium carbonate, $CaCO_3$) and alumina (aluminum oxide, Al_2O_3) are added.

Soda ash (sodium carbonate, Na_2CO_3) is used to reduce the melting point of silica, making the production process more energy-efficient, however, it also reduces glass's chemical durability, making it easier to dissolve in water, that is where limestone comes because it is used to enhance glass's durability and resistance to water, preventing it from degrading. Alumina is usually added to increase glass's resistance to scratches and chemical wear.

Depending on needed properties such as clarity, color, thermal or chemical stability and usage of glass, variation in the material can impact the final product [2].

However, there are also types of glass that are produced to resist high temperatures and temperature changes. These types of glass are produced for resisting fire and fire conditions for some period of time. They are used to make fire barriers since they provide visibility and safety in emergency situations.

2. Types of glass

Even though they may all look the same, there are different types of glass that are used in construction.

An important element of contemporary architecture and design, glass is favored for its adaptability, toughness, and visual appeal. Different forms of glass serve a variety of vital roles in buildings and interiors, from improving natural light to providing enhanced safety measures [3].

2.1 Float glass

Float glass is manufactured from sodium silicate and calcium silicate so, it is also known as soda-lime glass. This type of glass is clear and flat. Float glass is typically used in public places, such as windows and architectural glazing.

Windows are essential parts of a building since they serve an array of purposes such as providing a barrier between indoor-outdoor space while visible light admittance [4].

Additionally, float glass can be used as a base form of glass that manufacturers use to make other types of glass.

The most significant innovation in the flat glass industry is undoubtedly the development of the float process. As a result of its revolutionary impact on glass production, started the production of high-quality windows [4].

2.2 Annealed glass

Annealed glass is the fundamental output of the float glass. Once set up, it is steadily cooled in a controlled conditions to reduce internal stresses, decreasing the likelihood of breaking. It is commonly found in dual-pane windows, picture frames, and certain types of furniture. Annealed glass is undeniably the most frequently utilized glazing material in building construction [6]. Flat glass, now predominantly made through the float method, serves as the key fundamental material for contemporary glazing in various forms. It is specifically refined into insulating glass units (IGU), a widely used product in the construction industry for both window and facade applications. Annealed float glass is preferred due to its affordability and visual benefits over thermally pre-stressed glass. The application range for annealed glass is limited because of its lower edge strength [7].

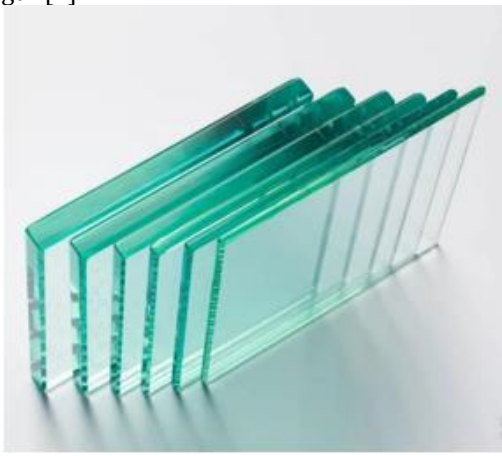

Figure 1. Float glass [5].

2.3 Heat-strengthened glass

Heat-strengthened glass is produced by heating annealed glass and subsequently cooling its surfaces, leading to compressed surfaces with a tensile core, resulting in a glass that is about two times stronger than annealed glass. In contrast to tempered glass, it does not shatter into small granular chunks. It is frequently utilized used in double-glazing where extra strength is required.

While glass is being more commonly utilized as a structural material, it is not manufactured to strength specifications, in contrast to steel and concrete. Among the various kinds of glass, only heat strengthened glass possesses the qualities to serve as a secure structural material. These characteristics include strength, resistance to stress corrosion cracking, and managed fragmentation [9].

2.4 Tempered or toughened glass

Tempered glass is made similar to heat-strengthened glass but with more rapid cooling of its surfaces, which results in compressed surfaces with tensile interior. This formulation enhances the strength of the glass, alters its fracture pattern, and renders the glass approximately four times stronger than annealed glass. Common uses include shower doors, car windows, and as safety glass in constructions.

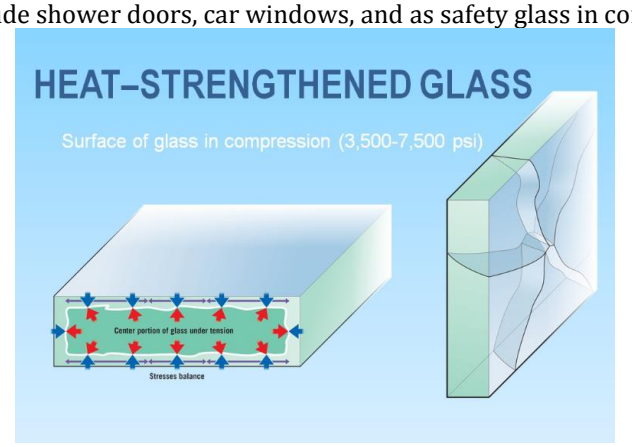

Figure 2. Heat-strengthened glass [8]

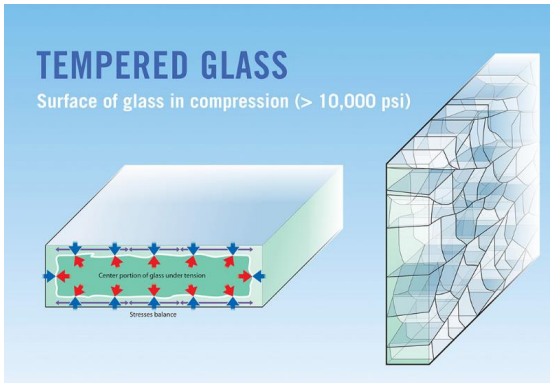

Figure 3. Tempered glass [15]

To enhance the mechanical qualities and thermal stability of tempered glass, the glass is heated to a specific temperature and then quickly cooled, is the simplest way to describe the production process. [10, 11]. Due to the glass's low thermal conductivity, the outer layer of the glass shrinks and hardens first as it is heated below the softening temperature in a heating furnace and then swiftly transferred to a cooling device where it is quenched with an appropriate pressure of normal temperature air flow. At this point, the interior of the glass is still at a high temperature [12]. The hardened outside layer will stop the inner layer from shrinking as the glass's interior starts to harden. This will result in tensile stress in the later hardened inner layer and compressible tension in the first hardened outer layer [13]. This portion of the compressible stress must first be neutralized when an external force applies on the surface, significantly increasing the glass's mechanical strength. As a result, tempered glass performs more effectively and has greater shock resistance. [14].

2.5 Laminated glass

Laminated glass is built of two or more sheets of glass fused together with an interlayer, usually composed of polyvinyl butyral (PVB) or ethylene-vinyl acetate (EVA). This interlayer serves to keep the glass layers bonded even when the glass is broken, which in the end provides additional security.

This type of glass is used in windshields, skylights, and architectural applications where safety and security are concerns.

PVB, SGP, PET, or ethylene vinyl acetate (EVA) films, as well as one or more pieces of annealed, float, tempered, colored, heat-strengthened, coated, or absorbent glasses, can all be found in a single laminated glass [17].

The following Fig. 5. shows the comparison of annealed, heat-strengthening, fully tempered and laminated breaking patterns.

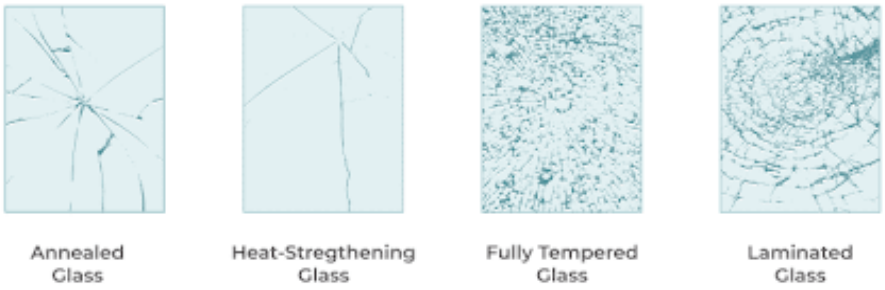

Figure 5. Comparison of annealed, heat-strengthening, fully tempered and laminated breaking patterns [18]

2.6 Insulated glass (Double-glazing glass)

To improve thermal insulation, insulated glass units (IGUs) are made up of two or more glass panels that are divided by air or inert gases such as argon or krypton. Usually, a high-strength sealant is applied to the edges to stop air and moisture intrusion. It is frequently utilized in windows for residences, workplaces, and tall buildings.

Double-glazed save thermal and electrical energy because they effectively isolate the interior temperature form the exterior one [20]. An insulated glass unit (IGU) merges several glass sheets into one window assembly. The majority of IGUs consist of double glazing (two layers of glass), while triple glazing (three layers) or more is increasingly prevalent due to rising energy expenses. The glass panes in IGUs are divided by a spacer and a stationary layer of air or gas. The glass is subsequently installed into window frames that are designed to hold the two panes [21].

2.7 Vacuum glass

An improved type of insulating glass is vacuum glass. It comprises two panels that are divided by an extremely thin space, from which air is removed to establish a vacuum. This vacuum gap is one of the best ways to insulate a window product because it significantly lowers heat transmission from conduction and convection. For energy-efficient structures in both the residential and commercial sectors, this glass is flawless. In general, two glass panes with an evacuated interstitial space make up vacuum glazing. In order to maintain the effectiveness of the glazing, a vacuum-sealed edge and a network of spacer pillars are essential. Because it drastically lowers the rates of convective and conductive heat transfer, vacuum glazing has excellent thermal performance. Vacuum glass products are lighter and have a shallower design than multi-pane insulation glasses with similar thermal performance. Nevertheless, employing vacuum glass in windows requires a serious reevaluation of the way windows are currently constructed, particularly in light of thermal bridges and the associated risk of surface condensation at the connections between the glass and the frame. In particular, the glass edge seal needs an insulating cover that is not included in standard insulation glass frame configurations since it can be thought of as the vacuum glass's weak point in terms of heat transfer [24].

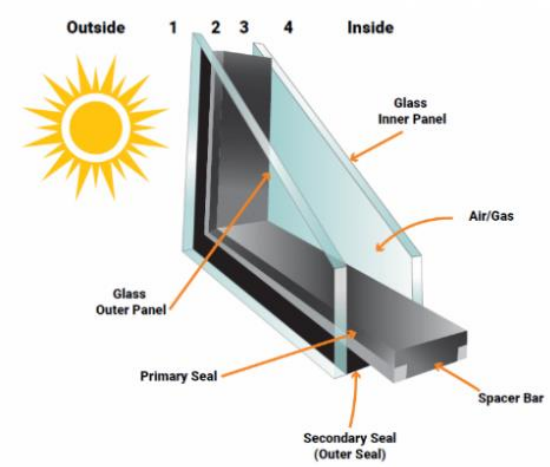

Figure 6. Insulated glass (Double-glazing glass) [19]

2.8 Wired glass

During the production process, a wire mesh is incorporated into the glass to create wired glass. Because it can stop glass from breaking at extremely hot temperatures, this wire mesh adds strength and is especially good at preventing fires. This glass can be used in skylights, fire-rated windows, and other locations that need additional safety.

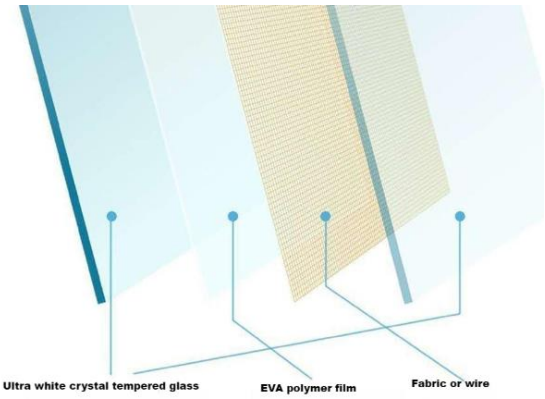

Figure 9. Wired glass composition [25]

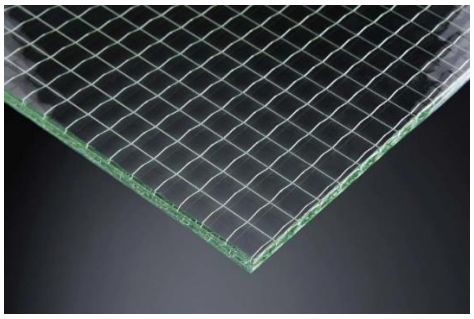

Figure 10. Wired glass [27]

Wired glass is a kind of glass that incorporates a wire mesh placed between two layers of hot semi-molten glass sheets during production. This kind of glass has been utilized for several decades and has been incorrectly referred as a safety glass, a misnomer associated with the common misconception that the wire mesh in the glass serves to provide mechanical support. In reality, wired glass was designed to function as a fire-resistant glass, as the wire mesh secures the glass in position as it softens due to increasing

temperatures from a fire and inhibits the spreading of both the glass and flames if the pane breaks during the fire [26].

2.9 Tinted glass

Metal oxides are added to float glass throughout the manufacturing process to give it color and improved sun control capabilities. This process produces tinted glass. Additional hues can lessen solar heat accumulation and glare. It is frequently used to regulate solar gain while offering privacy in cars, building facades, and decorative applications.

Figure 11. Tinted glass [28]

Tinted glass is essentially colored glass. Glass tinting reduces the clarity of what is ordinarily seen to the person looking through the window. Instead, the glass's deeper hue partially distorts the vision. The more tinted the glass, the darker it appears, so there is a range of how dark you might like the glass to be. While the glass is colored and the view is slightly obscured, it is still to see through the glass. However, it will not be able to distinguish details on the opposite side as well, which is one of the primary purposes of tinted glass.

2.10 Reflective (mirrored) glass

Reflective glass is made by adding a metallic reflective layer to glass. Usually composed of aluminum or silver, this coating is put on the rear of the glass to give one side a mirror-like appearance. Mirrors, furnishings, ornamental accents, and structures in sunny regions all involve it.

Figure 12. Reflective (mirrored) glass [29]

Transparent-reflective switchable (TRS) glass is an innovative technology that allows for active management of solar radiation. In terms of radiant energy regulation, efficient TRS glasses are superior to other smart windows, such conventional electrochromic glasses, because they adjust the transmission of sunlight according to light reflection, preventing needless heating of the interior by sunlight through the fenestrations. The significant tunability of translucence not only facilitates the adjustment of indoor temperature but also enhances glare management for building inhabitant's visual comfort. [30]

2.11 Low-Emissivity (Low-E) glass

Longwave infrared energy is reflected by the translucent, microscopically thin covering of low-E glass. Its main purpose is to make buildings more energy-efficient by lowering the quantity of heat that escapes through the glass. Energy-efficient windows in residential and business buildings look fantastic with this glass.

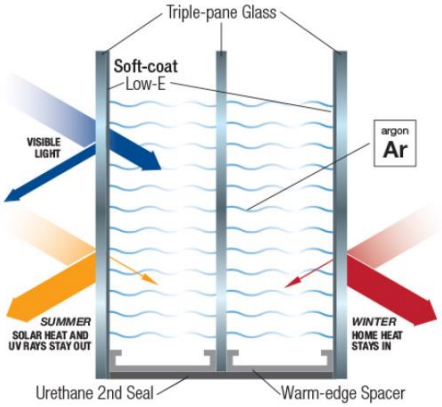

Figure 13. Low-Emissivity Reflective (Low-E)) glass [31]

Low emissivity glass, or low-E glass, is a type of low-emissivity material characterized high transmittance in the visible light range and significant reflection in the infrared region. Low-E glass is a common component in contemporary green building design because it offers superior indoor lighting and efficient thermal insulation. In discussions about energy and green building, it is highly respected [32]. When choosing low-E glass from commercially available products, consumers consider emissivity to be a critical factor. Better thermal insulation performance is indicated by a lower emissivity rating [33].

2.12 Patterned glass

Patterned glass has aesthetic textures or designs imprinted on one or both sides during manufacturing to alter the way light scatters. Common patterns include ribbed, fluted, frosted, and other complex patterns. Patterned glass is ideal for applications requiring both obscurity and decorative visual appeal, such as window privacy films, bathroom enclosures, room dividers, and interior doors.

Figure 14. Patterned glass [34]

2.13 Fire-rated glass

Fire-rated glass is designed to resist extreme temperatures for a specified amount of time while maintaining its structural integrity during a fire. As a key component of building safety regulations, fire-rated glass is commonly used in fire doors, internal partitions, and other structures to enhance fire resistance requirements.

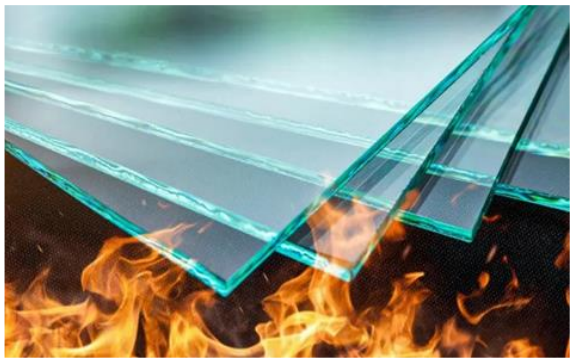

Figure 15. Fire-rated glass [35]

In general, fire-rated glass provides protection against flames, hot gases and smoke [36]. These glass items, occasionally referred to as fire-resistant or class E, encompass wired glass or specially tempered glass, sometimes borosilicate glass [37].

3. Conclusion

The diverse range of glass types available today underscores its critical role in modern architecture and construction, combining functionality, safety, and aesthetic appeal. Each type of glass is designed to address specific challenges and applications, making it an indispensable material in building design.

Standard float and annealed glass are foundational for general applications, offering cost-effective solutions for windows, doors, and interior elements. However, as the demand for safety and durability grows, tempered and laminated glass have become essential in areas where impact resistance and structural integrity are critical, such as automotive windows, facades, and safety barriers. Laminated glass, with its multi-layered construction, also enhances security and minimizes injury risks by holding together upon breakage. For energy-efficient and sustainable building designs, insulated and Low-E (low emissivity) glass are vital. Insulated glass, with its double or triple-pane structure, improves thermal insulation, reducing energy consumption for heating and cooling. Low-E glass further enhances energy performance by reflecting heat while maintaining natural light transmission, making it a preferred choice in green building initiatives.

Safety during fire incidents is another key area where specialized glass types play a pivotal role. Wired glass, with embedded wire mesh, provides stability under high heat, preventing shattering and maintaining barriers to smoke and flames. Fire-rated glass goes further by withstanding extreme temperatures for specified durations, ensuring safe evacuation and reducing fire spread. These properties make fire-rated and wired glass essential in fire doors, partitions, and windows in public and high-risk buildings.

The evolution of glass technology has expanded its design possibilities, allowing architects and engineers to create innovative and resilient structures that meet current standards and future challenges. By carefully selecting the appropriate type of glass based on environmental conditions, safety needs, and design objectives, architects and engineers can create innovative and resilient structures that meet current standards and future challenges. As advancements in glass technology continue, its role in modern construction will only grow, driving innovation and enabling the creation of structures that balance form, function, and safety.

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Rehabilitation of the road body of regional road R467a Kladanj–Brateljevici in the settlement of Omerćetovac

Amir Dedić[1], Mirza Memić[2] and Edis Softić[3]

[1] ATRIUS PROJEKT d.o.o Živinice, ul. Alije Izetbegovića ZPC Park
[2] JU Direkcija regionalnih cesta TK, A. Herljevića 43 Tuzla
[3] University of Bihać, Faculty of Technical Engineering, Bosnia and Herzegovina

E-mail: agora.arh@gmail.com

Abstract. Damage to the road structure can occur for various reasons. Most often, this is the impact of intense precipitation on the road structure, inadequate road maintenance, landslide activation, etc. Usually, the road structure is repaired by constructing supporting structures. The selection of the type of supporting structure largely depends on the input parameters obtained based on the engineering-geological characteristics of the soil, available space, financial capabilities, etc. In locations where the bearing soil is at greater depths, when the construction of standard types of supporting structures is not rational or not possible, the indirect foundation method is proposed. In this method, the supporting structure is made of an "L"-shaped wall founded indirectly on concrete elements - "buttresses", which rely on the bearing soil. This method represents the optimal solution for repairing the road structure in such conditions and is acceptable from several aspects because it has a lower economic value than the construction of the complete structure, while the execution technology is simplified. This paper discusses and describes the design elements of a retaining wall on "buttresses" as well as monitoring the progress of the road body rehabilitation project.

Keywords: Geostatic Calculations, Support Structures, Buttress, Damage, Repair

1. Introduction

The broader term “retaining structures” is now commonly used, as these structures are made from various materials, based on different structural systems, and serve a wide range of purposes [1].

In today’s construction practice, where the emphasis is on high-quality, cost-effective, and technologically simplified solutions, L-shaped retaining walls supported by buttresses fully meet these criteria, especially when the load-bearing soil is located at greater depths.

This paper presents a retaining structure—specifically, a retaining wall supported by buttresses—designed for a specific site. The process included preliminary engineering-geological investigations, analysis of alternative solutions, structural design, and execution of construction works.

2. Site investigations

As was the case across much of Bosnia and Herzegovina, the municipality of Kladanj also experienced widespread landslide activity in May 2014 following extreme rainfall. One such location where slope instability and damage to the existing road structure occurred was along the regional road R-467a Kladanj–Brateljevići, in the settlement of Omerćetovac.

In preparation for landslide remediation, relevant data were collected, including detailed geodetic surveys of the existing conditions, visual inspections, and engineering-geological and geomechanical investigations. Based on these investigations, the following key parameters were identified:

- Landslide geometry;
- Hydrogeological conditions;
- Geological composition and terrain characteristics;
- Geomechanical properties of the soil within and around the landslide zone.

Figure 1. On-site photographs.

Figure 2. Field photos – existing inspection manhole on the uphill side and road.

Through preparatory activities and investigative works conducted prior to the development of the project documentation, it was determined that one of the main causes of slope instability beneath the road embankment is the influence of groundwater and surface water originating from the hillside. This water flows uncontrollably along the roadway, combined with the torrential flow of the Drinjača River.

Such water infiltration contributed to the weakening of clayey materials in the road subgrade and slope embankment. Shortly after the landslide was triggered in 2014, emergency intervention measures were undertaken to stabilize the affected area. As part of these measures, a retaining structure constructed of crushed stone was built (Figure 3). Stormwater drainage was managed via open channels and curbs that directed water into existing manholes and concrete culverts (Figure 2), eventually discharging it into the receiving water body – the Drinjača River. However, no dedicated drainage system was installed. Groundwater also weakened the contact layer with the substrate, likely contributing to further ground movement on the downhill side of the road. The existing retaining structure has proven inadequate for ensuring full stabilization.

The primary causes of the landslide can be summarized as follows:

- Uncontrolled inflow and infiltration of surface water into the slope, i.e., the landslide zone;
- The influence of the nearby river and its torrential character;
- Seasonally variable inflow and flow of groundwater within surface cover layers and above the impermeable base, which reduces overall slope stability;
- Geological composition and structural characteristics of the slope;
- Based on the current stability assessment, the investigated area is classified as unstable and “in motion,” indicating an active phase of landslide development.

Figure 3. Site photographs – temporary stabilization measure by placing crushed stone fill.

Table 1: Geotechnical soil properties – sourced from [2].

Layer 1	HUMUS – clayey: SPT N-value = 6–7 blows, Ms = 1.8–2.1 MPa
Layer 2	CLAY – brown, fat, sandy, with limestone inclusions, inorganic, medium to high plasticity (CIH/CH): w = 21.58–23.18%, γ = 19.22–20.39 kN/m^3, Ic = 0.758–0.809, c = 17.43–62.41 kN/m^2, φ = 5.55–18.93°, Ms (at 100 kN/m^2) = 2.83–10.20 MPa
Layer 3	CLAY – grey, with sandstone inclusions, inorganic, medium plasticity (CI), subordinately high plasticity (CH): w = 20.41–26.59%, γ = 19.19–20.80 kN/m^3, Ic = 0.731–0.922, c = 15.46–45.28 kN/m^2, φ = 7.59–23.16°, Ms (at 100 kN/m^2) = 4.51–7.55 MPa
Layer 4	CRUSHED ROCK – limestone, subordinately sandstone, clayey: w = 12.60–17.96%, γ = 20.85–21.74 kN/m^3, c = 29.42–38.7 kN/m^2, φ = 20–37°, SPT N-value = 43 blows, Ms = 34.40 MPa
Layer 5	LIMESTONE – light gray-white, compact, very strong: w = 1.66–2.31%, γ = 25.48–25.59 kN/m^3, σ = 16.9–18.2 MPa

Three boreholes were drilled to determine the engineering-geological conditions on site and the geomechanical properties of the soil. During the investigations, light gray-white compact limestone was encountered at a depth of 6.5 m. Groundwater was observed at depths of approximately -1.0 m and -4.7 m [2].

Based on the described engineering-geological characteristics of the site, the comparison of laboratory test results from these investigations, and experience with similar materials, a geotechnical soil profile with design parameters was adopted, as shown in Figure 4 [2].

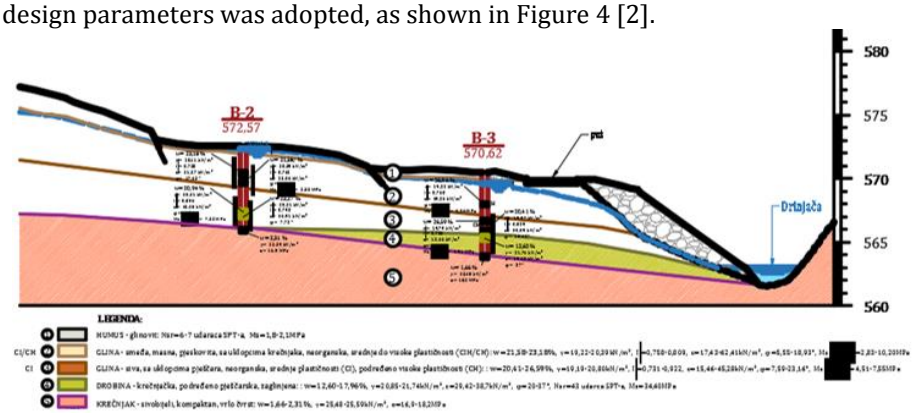

Figure 4. Engineering-geological site profiles [2].

3. Project solution

Taking into account the previously mentioned factors—particularly the depth of the substrate—and following thorough analyses and calculations, the proposed remediation model is an "L"-shaped retaining

wall, indirectly founded on counterforts (concrete elements bearing on the substrate). In this specific case, the counterforts are designed with an axial spacing of 6.0 meters and a sloped base footing that provides additional anchorage into the substrate. The excavation depth for the counterforts must extend at least 30 cm into the substrate [3]. This type of remediation system is especially suitable for terrains where bearing soil is located at greater depths, as is the case here.

On the hillside side of the road, a 200 mm diameter drainage pipe is planned, discharging into inspection chambers. Additionally, a weep hole system (barbican) is incorporated into the wall to reduce hydrostatic pressure and drain the entire, highly unstable area. The entire slope surface between the roadway and the retaining wall will be covered with large crushed stone.

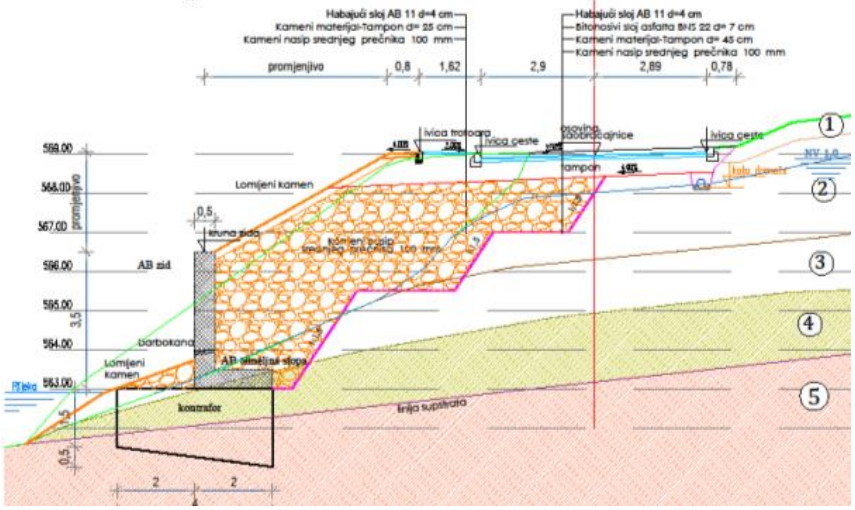

Figure 5. Cross-section of the retaining wall with counterforts [3].

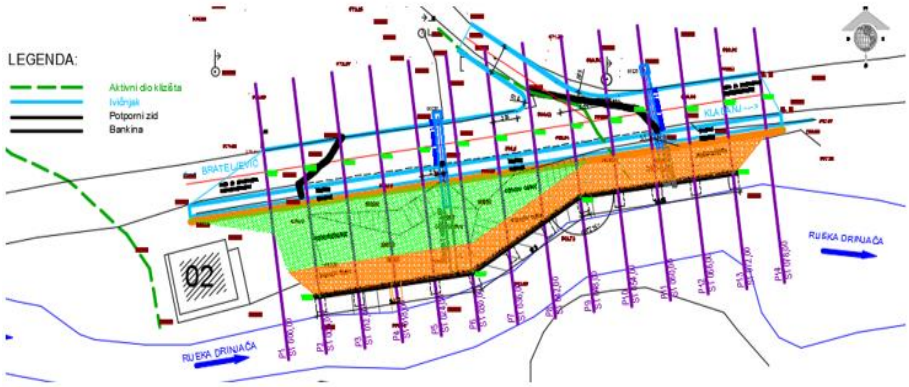

Figure 6. Site conditions – Design solution [3].

4. Geostatic analysis

For the proposed retaining structure, it is necessary to verify the safety factors against sliding and overturning, as well as to size the structural elements. The active earth pressure coefficient was determined according to Rankine's theory. The surface effect of traffic loading was also taken into account.

Table 2. Geotechnical soil properties used in the calculation

Layer 3	Layer 5	Rock fill
w= 26,59 %	w= 12,60 %	γ=18,0 kN/m^3
γ= 19,79 kN/m^3	γ= 21,74 kN/m^3	c= 0 kN/m^2
Ic= 0,786	c= 29,42 kN/m^2	φ= 32°
c= 15,46 kN/m^2	φ= 37 °	
φ= 14,04 °		

4.1 Wall calculation model

b1= 2 m
b2= 1.5 m
b3= 0 m
bz= 0.5 m
Bk= 4 m
Bt= 2 m
Hn= 0.9 m
Hz= 3 m
Ht= 0.5 m
H= 3.5 m
Hs= 0 m
Hk= 1.5 m
He= 4.4 m
β= 31°
P = 10 KN/m²
angle α = 20°
Center-to-center spacing of counterforts = 6,0m
Width of the counterfort = 1.5 m

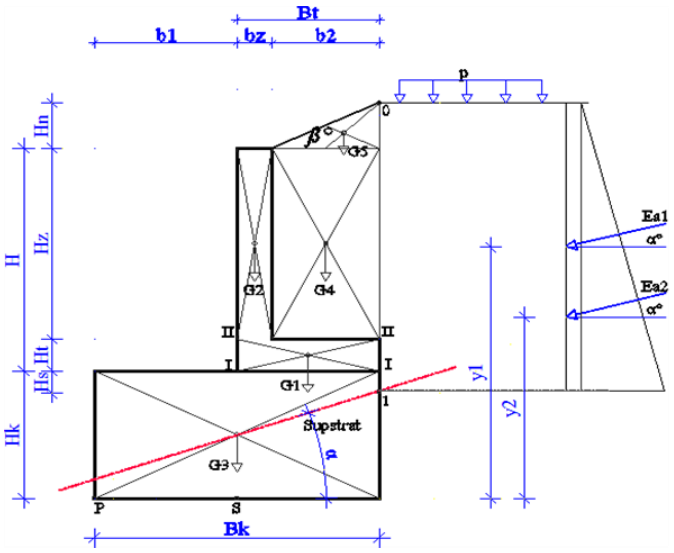

Figure 7. Calculation model of the retaining wall.

4.2 Reduction of Forces on the Counterforts

The technical design foresees a retaining wall supported by counterforts spaced 6.00 meters center-to-center. The counterforts are embedded in the substrate and have a width of 1.50 meters. Therefore, it is necessary to apply a reduction to the active and passive earth pressure forces, as well as to the self-weight of the wall.

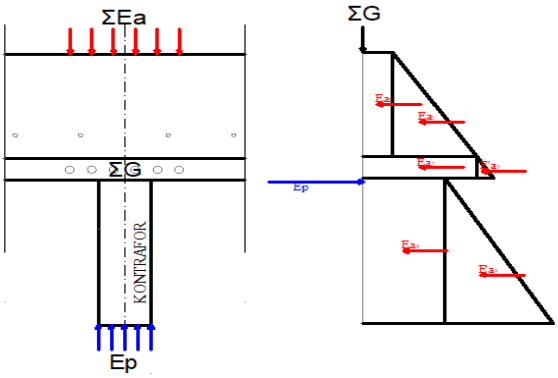

Figure 8. Force reduction per individual counterfort.

4.3 Calculation results

After completing the geostatic calculations, all required stability factors were confirmed, and the structural elements were dimensioned.

The factor of safety against sliding, Fsk_{sk}sk = 1.72 > 1.5.

The factor of safety against overturning, Fsp_{sp}sp = 2.48 > 1.5.

Based on the static effects at joint II-II, which are relevant for wall dimensioning, the required main reinforcement was adopted as Φ16/8 cm and distribution reinforcement as Φ10/25 cm. For the outer surface of the wall, structural reinforcement MAR Q335 was selected.

In the connector I-I relevant for foundation dimensioning, the necessary load-bearing and split reinforcement Φ14/8 cm was adopted.

The connection between the wall and counterforts was also dimensioned, with reinforcement adopted as ± Φ14/16 cm. The reinforcement plan for the wall and counterforts is shown in the cross-section in Figure 9.

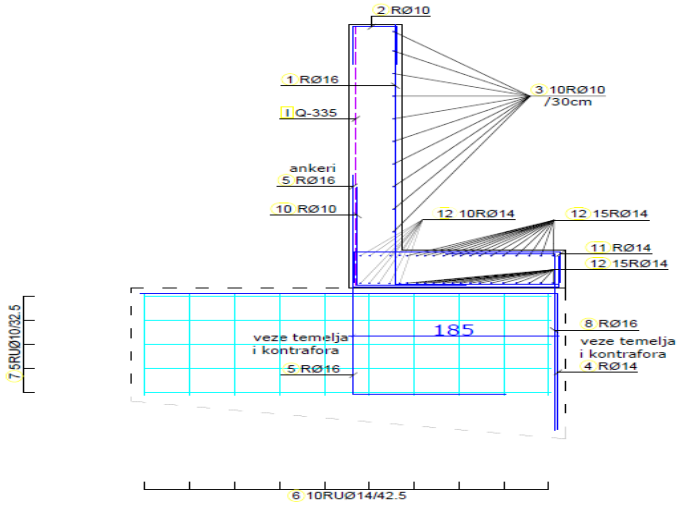

Figure 9. Reinforcement plan in the cross-section [3].

5. Construction process of the retaining structure

Based on the project documentation, remediation works were initiated. Following the removal of materials previously used for emergency repair measures (see Figure 3), excavation and site preparation commenced for the construction of the counterforts and the initial phase of the retaining wall, as illustrated in Figure 10.

Figure 10: a) First stage of the wall b) Reinforcement for the connection between the counterforts and the wall foundation

Considering that the works are carried out in the riverbed, the project documentation specifies that construction should take place during the period of hydrological minimum.

Figure 11: a) Wall stage

b) Construction of stone cladding

Figure 12: a) Roadway works

b) Site restoration after wall completion

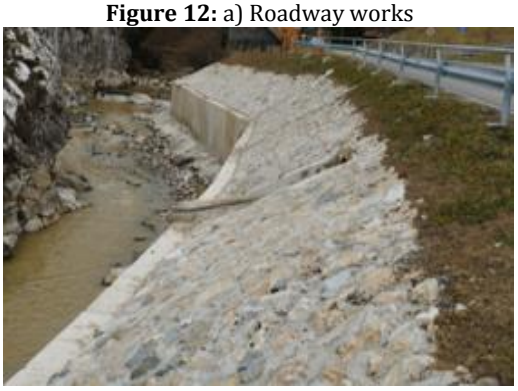

Figure 13: a) Completed wall

b) Completed wall and outlet structure of the culvert

6. Observations and conclusions

The construction of a retaining structure indirectly founded on counterforts requires a comprehensive analysis of all factors relevant to its stability. Through geostatic calculations and verifications, it is essential to demonstrate all safety factors to ensure that the structure performs safely during its service life. A key prerequisite is the high-quality execution of construction works, which is to be ensured by assigning the project to an experienced contractor under mandatory professional supervision.

Given the complexity of such geotechnical structures, continuous monitoring of spatial displacements (both vertical and horizontal) over time is necessary. An initial "zero" measurement must be taken immediately after the remediation works are completed. Two years after the completion of this specific structure, no deformations have been observed, confirming that the proposed remediation model—an "L"-shaped retaining structure founded on counterforts—is fully adequate as a technical solution for this case.

From an economic perspective, construction analysis shows that this is a highly acceptable solution. Significant savings are achieved in both reinforced concrete and earthworks, making the proposed model not only rational but also highly cost-effective.

The implemented remediation measures will significantly enhance the secondary stability of both the slope and the roadway. The presented model can serve as a practical example for addressing similar cases in the field.

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Significance of excavation for the water reservoir of the recreation center in Cazin

Edis Softić[1], Nazif Keranović[2], Amir Dedić[3] and Mirsad Ičanović[4]

[1] University of Bihać, Faculty of Technical Engineering, Bosnia and Herzegovina
[2] BH_DRAWING doo Cazin, Bosnia and Herzegovina
[3]ARIUS PROJEKT doo Živinice, Bosnia and Herzegovina
[4] University of Bihać, Biotechnical Faculty, Bihac Bosnia and Herzegovina

E-mail: edissoftic@unbi.ba

Abstract. The paper gives a brief overview of the significance and role of earth excavations, primarily for the execution of earthworks for the water reservoir of the sports recreation center in the settlement of Kličići, municipality of Cazin. The aim of the above is to know the engineering geological, hydrogeological and geomechanical characteristics of the terrain in question, with a focus on review of the basic geotechnical conditions for the construction of access roads within the complex, accompanying business facilities (restaurant and bar) and the construction of an artificial lake at the location in question with a proposal for a construction solution.

1. Introduction

The paper presents the engineering-geological and geomechanical investigations of the terrain for the construction of the business-recreational complex "Oaza Bare" in the populated place Kličići, more precisely in the part of the settlement called Bare.

The execution of the works and the creation of geological project documentation was carried out due to the knowledge of the engineering geological, hydrogeological and geomechanical characteristics of the subject terrain, with the aim of assessing the basic geotechnical conditions for the construction of access roads within the complex, accompanying business facilities (restaurant and bar) and the construction of an artificial lake in the subject terrain. Regarding the goal of the research, the geotechnical risks related to the location and the type of work that will be carried out were pointed out with recommendations for optimization, adaptation to the conditions in the field and the technology of insurance and foundation/construction, which are ultimately decided by the Designer, Supervision and Investor. [4]

2. Existing condition of the terrain and location

The network of roads and communal infrastructure within the future construction area is currently not built, these are mainly agricultural properties with pastures and meadows with rarely overgrown tall trees. The area is a "delta" of two streams (Čelar and Kličići, which in that part form a swamp of approx. 5 ha). The Čelar stream flows from the settlement of Polje in a northeast-southwest (NE-SW) direction to the location in question, while the Kličići stream flows directly below the settlement of Gnjilavac in the direction of north-northwest-south-southeast to the location in question. It can be noticed that in the immediate area there are several catchments-springs which often decrease considerably during the summer period and even dry up.

The realization of the task saw and defined the following:

- geological, engineering geological and hydrogeological characteristics of the terrain;
- physical and mechanical properties of soil/rock;
- a geotechnical terrain model was established with recommendations for geotechnical conditions;
- securing and foundation of facilities
- geotechnical risks were considered.

3. Types and scope of performed works

3.1. Field observation and investigative excavations

The basic documentation that was used in the analysis of the subject area is the Basic geological map 1:100,000, the Bihać sheet with an interpreter, as well as other available documentation related to the subject area, and considering what has been done, this area can be treated as well explored. In the process of creating the "Engineering Geological-Geomechanical Study" for the subject complex, the following investigations were carried out, which included:

- engineering geological prospecting and field observation;
- performing investigative excavations
- dynamic drilling - performing easy dynamic penetration DPL i
- elaboration of collected data and obtained results.

Prospecting was carried out situationally on a scale of 1:1000, and in addition to observing the terrain, determination/mapping of the wider subject area was carried out, as well as photography of investigative works. Within the engineering geological map with the location of exploration works, engineering geological profiles are also indicated.

A total of 10 (ten) exploratory excavations were carried out for the purpose of researching the area in question, marked as R-1, R-2, R-3, R-4, R-5, R-6, R-7, R-8, R-9 and R-10. Excavations/excavations were done mechanically, with a backhoe, in the foundation/construction zones of future roads within complexes and business buildings. Excavations were carried out with the aim of defining the lithological/geological composition and visual properties of the soil/rocks of the subject terrain, and after the excavation, geological determination (mapping) and photography were carried out, and then the excavated materials were returned to the excavated pits. The depth of the excavation went much deeper than is necessary to define the geotechnical conditions of the foundation, that is, the excavation mainly went to the basic rock mass (dolomite), which in this microlocation is at a depth of approximately -3.0 m. [2,4,5]

3.2. Performing light dynamic penetration DPL

In order to realize the task, 5 (five) light dynamic penetration tests were carried out in the zones of the future road and business buildings (restaurant and bar), i.e. dynamic drilling of markings DPL-1, DPL-2, DPL-3, DPL-4 and DPL-5, individual depths from 2.10 m to 4.20 m (appendix 4).The purpose of this test is to determine the resistance of the soil (base medium) by penetrating a standardized cone, i.e. the consistent state or compaction/bearing capacity.

Figure 1. Carrying out exploratory excavations at the positions of the future water reservoir. [4]

Dynamic penetration drilling (DPL) was performed by continuously penetrating and recording the compaction value every 10 cm of depth, until the resistance of the cone during penetration did not exceed the number of blows greater than 30 (Figures 2 and 3).

Figure 2. Schematic representation and execution of probing with a light dynamic penetrometer at the location in question. [4]

The DPL tests were processed in the Dynamic Probing program, and were given in a report and shown in diagrams of static soil resistance, with the establishment of correlations according to the values of 1 DPM = 0.51 SPT, and were used together in the processing, analysis and interpretation of research data in this work.

4. Research results

The wider investigated area is characterized by a complex geological structure due to a very heterogeneous lithofacies composition and tectonic structure. The basic geological structure of the wider area of the subject location is made up of sediments of Triassic (T3) and Jurassic age (J2,3), the total thickness of which is about 800 m, and they are covered by various genetic types of Quaternary sediments (Q).

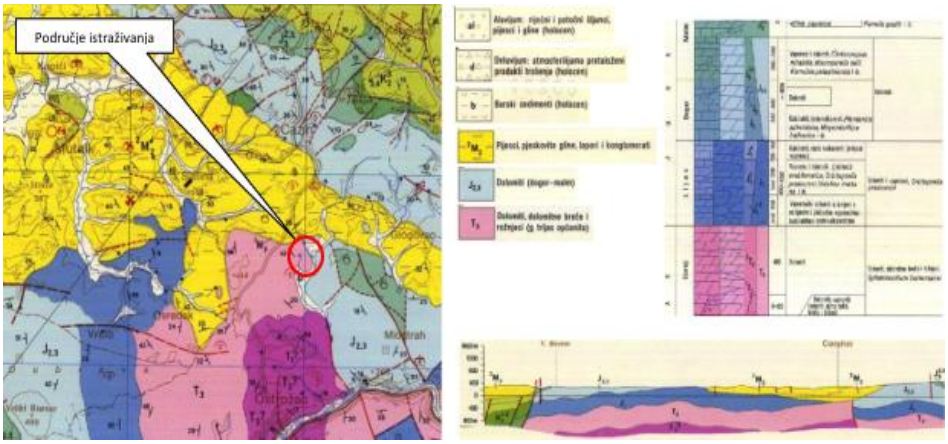

Figure 3. Geological structure of the wider research area (used OGK, sheet Bihać, M 1: 100,000, SGZ Belgrade, 1976). [7]

4.1. Tectonic structure and seismotectonic characteristics

The terrains in question are characterized by a complex structure that is mainly formed by rupture deformations (all types of faults). Larger faults represent the boundaries of tectonic units and have mainly the Dinaric direction. Structurally, the area in question belongs to the Mesozoic tectonic unit Gata-Ostrožac. According to the above map, in the area of Cazin, as well as in the wider zone of the research location, for a return period of 500 years and with a probability of occurrence of 60%, earthquake intensities of 7^{o} MCS, or EMS scale, are expected.

The form on the basis of which the return period of the occurrence of an earthquake (Tp) can be determined, as well as which seismological map should be used for the given exploitation life of the specific object (t), along with the expected risk (R), reads:

$$T_p = \frac{-t}{1n(1-R)}$$

Table 1: Degree of seismicity for the wider research area [1]

Return period (Tp = 101 years)	Seismicity level (MCSo scale)
50	6^0
100	6^0
200	6^0, 7^0
500	7^0
1000	7^0, 8^0
10000	9^0

It follows that in the area of the subject terrain of Cazin, for the given exploitation life of t = 60 years and the magnitude of risk R = 10%, a seismological map should be used for a return period of 500 years, with a basic level of seismicity of 7^0 MCS increased by one 10 and with 0.10 g of seismic acceleration.

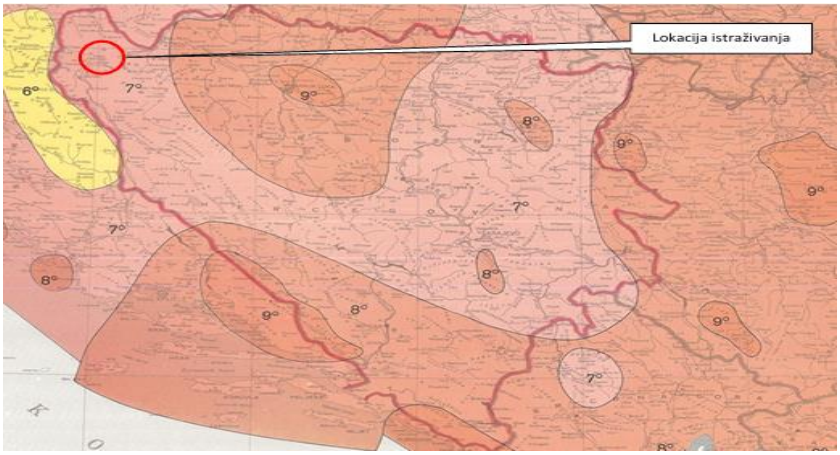

Figure 5 Seismological map of the SFRY for a return period of 500 years, M 1:1 000 000" (Seizmology . SFRY, Belgrade, 1990.).

Following the presentation of seismic characteristics, it is necessary to review the seismic hazard and risk of the given terrain. The definition of seismic hazard serves to determine the acceptable seismic risk that constitutes a space with a tight coupling of terrain as a natural environment and a created system of various artificial objects.

At the same time, the general stability should not be endangered. The assessment of seismic hazard, that is, the basic level of seismic intensity, is made on the basis of valid seismological maps and the seismotectonic map of Bosnia and Herzegovina. Since 1987, for the assessment of the reference earthquake for certain areas, seismological maps have been used that show the intensity of earthquakes whose probability of occurrence is at least once in that time period and amounts to 60%. This means that the given period of exploitation is equal to the return period of the earthquake.

4.2. Hydrogeological characteristics

Within the analyzed area, a number of water phenomena were recorded, including two surface watercourses, an artificial water accumulation (lake), baruštine (swamp) and three captured springs. The surface watercourses that flow through the location in question and which form a marshland with their flow are the Čelar stream, whose source is the Kličići stream in the settlement of Polje, which springs directly below the settlement of Gnjilavac. These are smaller streams that flow practically through the plain parts and the estimated yields are 5-10 (l/s). Both streams have a laminar (calm) flow, so they are rarely cloudy, and due to the low dynamics (power) and speed of the flow, mainly small particles, clay, silt (dust) and sand are deposited in their bed (alluvial) valley, forming silt, which was established by research. At the time of the research, an artificial accumulation was recorded in the central part of the baruština-swamp, i.e. a lake that was created by cleaning and excavation, as the beginning of the realization of the final project, a lake for recreation (swimming). The current depth does not exceed 1.0 m, and it is fed by the touching waters of two streams. The current water level in the lake is maintained at approximately -0.5 m from the ground surface, that is, up to the height of the humus cover (humus-clay dust contact), which is porous even when the water drains through the humus.[9]

Table 2: Water permeability by soil/rock type [7]

Soil/rock type	Filtration coefficient k_f (m/s)	Soil/rock characteristics
Clay monolithic solid rocks	$< 6 x^{-10}$	practically waterproof
Silts, heavy silts, compact, uncracked sandstones	do 6×10^{-8}	very poorly permeable
Sandy loams, weakly fractured shales, sandstones, limestones	do 6×10^{-6}	poorly permeable
Sands, dusty and fine-grained, cracked solid rocks.	do 6×10^{-5}	water-permeable
Medium-grained sands, solid rocks with increased porosity	do 6×10^{-4}	well permeable
Gravels and gravel, very cracked solid rocks	$> 6 \times 10^{-3}$	very water permeable

4.3. Engineering geological characteristics of the terrain

The terrain of the wider zone of the subject location of the future complex was assessed as unstable (Table 5, level of suitability 3 and 4) due to the fact that these areas are built by marsh sediments, i.e. terrains that have a constant water level (flooded terrain), a significant presence of organic soils (silt, clay), which are compressible, furthermore, a constant change in the water level when constant cycles of drying and saturation in the represented soils can cause subsidence and swelling of the material, but also the presence of organic substances, when during chemical decomposition the soil changes structure and causes deformations.[4]

Figure 6. Clay du st lithological/geotechnical environment 1ª.[4]

Table 3: Suitability of the terrain for the construction of facilities according to the lithological composition [3]

Level of convenience	Lithological composition of the terrain
I. Optimally favorable terrains (terrains without any restrictions for construction)	Lithological composition of the terrain Terrains built from lithological types and complexes of hard and soft rock masses and terrains built from unbound and semi-bound soil groups GW, GP, SW and SP USCS classification
II Favorable terrain (terrains with minor restrictions that can be solved without major difficulties)	Fields built from unbound and semi-bound soil groups GM, GC, SM, SC, ML and CL USCS classification
III Conditionally favorable terrain (terrains with greater difficulties that can be economically solved)	Fields built from unbound and semi-bound soil groups MH, CH, UL and OH USCS classification
IV Unfavorable terrain (terrains with very great difficulties that require major and expensive technical interventions)	Terrains made of all easily soluble rocks, wastelands and the Pt group of the USCS classification

[4]Investment and technical documentation of the Bare business and recreational center in the Kličići settlement

Table 4: Suitability of the terrain for the construction of buildings according to the occurrences of contemporary geological processes and seismicity [3]

Level of convenience	Occurrences of landslides, landslides, landslides and flash floods	Flooding phenomena	Seismicity of the terrain according to the MCS scale (in degrees)
I optimally favorable terrain	without the occurrence of landslides, landslides and flash floods	without the appearance of flooding	<5

II favorable terrain	with very rare and small occurrences	with very rare occurrences	5-6
III favorable terrain	with rare major and numerous minor occurrences	with rare occurrences	6-9
IV unfavorable terrain	with frequent and large occurrences	with frequent occurrences	>9

5. Calculation of soil bearing capacity considering its characteristics

The geotechnical model of the terrain in question, based on research, determination, testing and comparison with similar materials from the immediate environment or with similar lithological structure, analogies and literature knowledge as well as experience, is presented below:
LITHOLOGICAL/GEOTECHNICAL (MIDDLE 0)
- organic humus loams, brown to dark in color - humus 0.0 m – 0.9 m, the recommendation is as follows: replacement - crushed stone, replacement material $\varphi \approx 39°$; $c \approx 0$ kPa; $\gamma \approx 20.5$ kN/m^3 (substitute material parameters)
LITHOLOGICAL/GEOTECHNICAL ENVIRONMENT 1a
- clay dust with rare fragments of fine sandstone, yellow-brown and grayish in color, soft to normal consistency and high to extremely high plasticity, impermeable - alluvium/deluvium $\varphi \approx 23.5°$;
$c \approx 15$ kPa; $\gamma \approx 18.5$ kN/m^3 0.5 m – 2.3 m
LITHOLOGY/GEOTENICS. MIDDLE 1b
- dusty (silty) clays, grayish-blue in color, soft consistency and high to extremely high plasticity, impermeable to water - alluvium $\varphi \approx 23°$; $c \approx 13$ kPa; $\gamma \approx 19$ kN/m^3 0.9 m – 4.3 m
LITHOLOGICAL/GEOTECHNICAL ENVIRONMENT 1c
- fine-grained to medium-grained dolomite crumb, weakly carbonized and weakly compacted, water-permeable - alluvium $\varphi \approx 35°$; $c \approx 0$ kN/m^2; $\gamma \approx 20.0$ kN/m^3; 2.2 m – 4.6 m
LITHOLOGICAL/GEOTECHNICAL ENVIRONMENT 2
- cracked and eroded dolomite (significantly gravitized) T3 – weathering crust of the base rock $\gamma \approx 27.5$-28.5 kN/m^3, σ= 50-100 MPa, E = 7000 – 10000 MPa >2.6 m
Below 4.7 m (R-1) and 4.2 (DPL-5) depth, no research and field tests were carried out.

5.1. Calculation of the bearing capacity of the foundation according to the criterion of failure of the foundation soil for the basic and supplementary load

SOIL PARAMETERS:
- internal friction angle =24°
- cohesion = 15 kN/m^2
- wet weight = 18.5 kN/m^3
- immersed spatial weight = 8.5 kN/m^3

SAFETY FACTORS:
- for friction angle $F\varphi$ =1.50
- for cohesion F_C = 2.50
- φ_m = 16.2°
- Cm = 6.0 kN/m^2

GEOMETRIC CHARACTERISTICS:
- width of foundation strip B =0.60 m, B' =0.60 m, a_γ =0.46
- foundation depth D = 1.00 m
- depth NPV =0.00 m, N_q =4.40, d_c =1.41

LOADS: Nc =11.74, dq =1.31
- surface load p=0.0 kN/m^2 Nγ =1.78, k =1.03
- geological load s= 8.5 kN/m^2

- eccentricity of the resultant e =0.00 m s_c = sq = s_γ =1.00
width of the foundation strip B: (m)

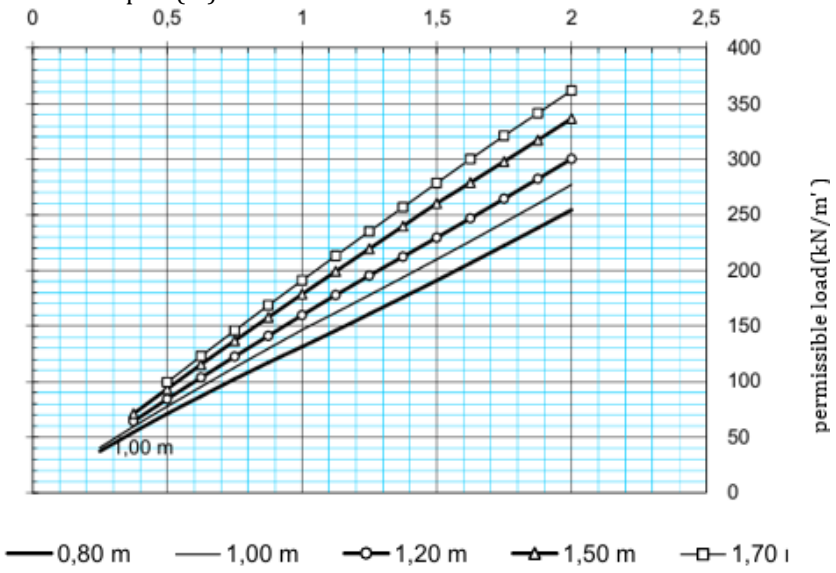

Figure 7. Permissible force on the ground.[4]

5.2. Calculation of the bearing capacity of the base rate according to the criterion of the failure of the foundation soil for the basic and supplementary load, without eccentricity

SOIL PARAMETERS:
- internal friction angle φ =23.5°
- cohesion C=15 (kN/m²)
- wet density γ=18.5 kN/m³
- immersed spatial weight γ' =9 kN/m³

SAFETY FACTORS:
- for friction angle F_φ =1.50
- for cohesion F_C =2.50

TENSION
- surface load = 0 kN/m²
- geological load = 4.5 kN/m²

GEOMETRIC CHARACTERISTICS
- foot width = 1 m
- foot length = 1 m
- foundation depth D =0.5 m
- depth NPV =0 m Calculation coefficients

Nc = 11.74; B' = 1 m; s_c =1.38 a_γ =0.49 N_q =4.40 L' =1 m s_q =1.29 k =0.39 N_γ =1.78
d_c = 1.16; s_γ =0.60; d_q = 1.12

The permissible contact pressure of the base foot on the ground, without the influence of horizontal force, for the given geometry, for the basic + supplementary load is: σ_{DOP} = 146 kN/m².
Force on foundation V_{DOP} = L'B' σ_{DOP} = 145,502 kN

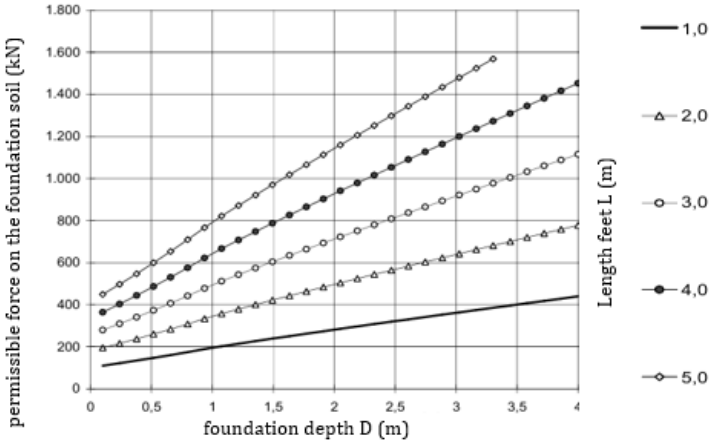

Figure 8. Graphical display of load capacity for the above measures and parameters.[4]

6. Conclusion

In accordance with the previously elaborated, and in accordance with the geomechanical characteristics as well as the conditions present in the field, for the needs of the foundation of the facility and possible securing of the construction excavation, it is recommended:

- Alluvial and alluvial-deluvial sediment materials (environments 1a, 1b and 1c) according to the above, represent environments that are not suitable for the direct foundation of facilities with significant loads, and in this specific case, certain replacements with suitable stone aggregate should be carried out by achieving the appropriate load-bearing capacity.
- Adopt a seismicity of the terrain of 8° MCS with a seismic acceleration of 0.10 g.
- It is necessary to carry out high-quality foundation of traffic roads within the Oaza complex, because the traffic roads will not only function as walkways, but also as service roads when, in certain situations, work machines and material with significant loads will need to be brought to these roads in the case of servicing existing facilities or construction (expansion) of new facilities, depending on the need
- in the zone of future buildings, the thickness of weakly load-bearing horizons is up to 3.0 m, under which well-bearing sediments lie, i.e. the basic rock mass dolomites, carry out replacement up to middle 1c (crumbs), and the extracted materials of middle 1a and 1b recognizable as waterproof clay and dust are used to insulate the bottom and rim of the future lake, fill the construction pit with replacement material using granulated material (crushed stone, crushed stone) the most suitable limestone or dolomite crushed stone 32 mm - 300 mm
- granulometric analysis of the selected samples revealed that they are impermeable clayey and dusty soils whose permeability coefficient is k

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Monitoring the development of concrete strength using a sclerometer

Anes Pajalić, Emina Dekić, Hasan Crnkić, Adna Muratović, Amela Japić and Emin Kozlica

University of Bihać, Faculty of Technical Engineering, Bosnia and Herzegovina

E-mail: anes.pajalic25@gmail.com

Abstract. This study focused on assessing the surface hardness of concrete cubes made with and without the addition of chemical admixtures. The testing was conducted using a Schmidt hammer (also known as a rebound hammer), which measures the surface hardness of concrete and provides an indirect estimate of its compressive strength. The concrete cubes were prepared under controlled laboratory conditions. Some mixtures included additives such as plasticizers, while others were plain reference mixes without any additives. After a curing period (typically 28 days), the Schmidt hammer was used to test multiple points on each cube, and the average rebound number was calculated. The results showed that concrete cubes containing additives generally exhibited higher rebound numbers, indicating greater surface hardness. This suggests that additives, especially those that improve workability and reduce water content—can enhance the density and strength of the concrete.

1. Introduction

The development of concrete strength represents a key aspect in quality control and the management of reinforced concrete construction. Although compressive strength testing on standardized cubes using destructive methods is the most reliable indicator, this method is time-consuming, destructive, and limited to laboratory samples. Therefore, the sclerometer method can also be used as a fast and non-destructive alternative. In the recent past, there has already been discussion about monitoring concrete strength using a sclerometer [1] [2]. In general, when it comes to concrete mixes, the use of additives such as fly ash is becoming increasingly common [3]. This work will use European standards. Initially, it is necessary to know how to calculate the concrete mix design and then cure the concrete after production [4] [5]. Standards that define requirements for destructive testing will be used for testing with a hydraulic press [6] [7]. For non-destructive testing with a sclerometer, standards that prescribe the procedure for determining concrete quality through sclerometer rebound will be applied [8] [9]. The effects of additives on concrete mixes will also be monitored using standards that define different types of admixtures and set quality requirements [10].

The aim of this paper is to demonstrate the possibility of using a sclerometer to monitor the development of concrete strength over time, with a particular focus on comparing the results with classical sample testing using a press. Through the experimental section, results will be analyzed at multiple time points, and the discussion will focus on the accuracy, repeatability, and deviations of the observed values.

2. Experimental methodology

The aim of the experimental methodology in this study is to monitor the development of concrete strength over time using a sclerometer. The methodology focuses on tracking changes in the surface hardness of concrete, which is related to the development of compressive strength.

2.1 Mix design and preparation procedure

To achieve the desired properties of concrete, proper preparation of the mix is essential. This involves selecting appropriate materials and determining their proportions. This section discusses the mix design of the concrete mixtures used, as well as the details of the preparation process — from dosing the required quantities of materials to the final mixing.

For the purpose of this study, two concrete mixtures were prepared. They differed only in the presence of an admixture. Table 1 shows the mix design used for producing the concrete cubes. The mix was calculated for a water-cement ratio (w/c) of 0.5.

Table 1. Concrete mix design for a water-cement ratio w/c = 0.5.

Material	Quantity
Cement [kg]	350
Water [l]	175
Aggregate 0-4 mm [kg]	1328,34
Aggregate 8-16 mm [kg]	664,17

Based on the data from Table 1, the quantities of materials for three cubes can be calculated. The composition of the first concrete mixture, labeled as M1, is shown in Table 2.

Table 2. Composition of concrete mix M1 for three cubes.

Material	Quantity
Cement [kg]	4,2525
Water [l]	2,12625
Aggregate 0-4 mm [kg]	16,1393
Aggregate 8-16 mm [kg]	8,0696

Na sastav betonske mješavine M1 dodati su još dodaci Pantafloor i SRA 100 i tako je nastala betonska mješavina M2, čiji je sastav i količina materijala prikazana u tabeli 3.

Table 3. Composition of concrete mix M2 for three cubes.

Material	Quantity
Cement [kg]	4,2525
Water [l]	2,12625
Aggregate 0-4 mm [kg]	16,1393
Aggregate 8-16 mm [kg]	8,0696
Pantafloor [ml]	29,77
SRA 100 [ml]	42,53

Pantafloor and SRA 100 are special admixtures used to improve the workability of concrete. Pantafloor is a superplasticizer that directly enhances the workability of concrete without increasing the water content. The recommended dosage is 5–7 ml per 1 kg of cement. In this calculation, 7 ml was adopted. SRA 100 is an admixture that reduces drying and shrinkage of concrete. The recommended dosage is 5–15 ml per 1 kg of cement. In this calculation, 10 ml was adopted.

Figure 1. Composition of mixtures M1 (left) and M2 (right).

Figure 1 shows the preparation of material quantities for mixing the M1 and M2 mixtures. Once the ingredients were prepared according to the previously specified amounts, the concrete production process began. First, M1, which contains no admixtures, was prepared. An equal amount of fine and coarse aggregate was added to the mixing container along with some cement until a uniform mass was obtained. Then, water was gradually added, and after mixing, the remaining aggregate was added. The mixture was then poured slowly into molds in layers and compacted by vibration. The preparation procedure for mixture M2 was the same, except that the specified amount of admixture was added along with the water. The concrete mixtures remained in the molds for 24 hours. Afterward, the now hardened cubes were removed from the molds and submerged in water, as shown in Figure 2.

Figure 2. Cubes submerged in water.

The sclerometer testing began in the construction materials testing laboratory at the Faculty of Technical Studies in Bihać, seven days after the concrete mixtures were prepared, specifically on April 22, 2025.

2.2 Testing

For the first part of the testing, a PCE-HT-225A type sclerometer was used, as shown in Figure 3. This device was selected for testing because its use is non-destructive to the tested sample. It is commonly used in construction practice to determine the strength of concrete. To assess concrete strength, an elastic force is applied that transfers impact energy to the surface of the concrete. Part of this energy is absorbed by the concrete, while the other part is reflected back to the hammer. This reflected energy is proportional to the surface hardness of the tested concrete. The hammer rebounds to a certain height, which is then used to estimate the concrete's compressive strength.

Figure 3. Sclerometer type PCE-HT-225A used.

The testing was conducted in accordance with the BAS EN 12504-2:2022 standard, which provides detailed instructions for preparation, operation, and result interpretation. The cube samples were previously dried and cleaned of dust and other impurities, as shown in Figure 4. A flat surface of the cubes and a flat base beneath them were ensured to allow for more accurate results. On each sample, 9 points were selected, symmetrically arranged in a 3x3 grid, avoiding the edges and any existing voids on the cubes. The sclerometer impacts were applied in a vertical position, perpendicular to the top surface of the cube.

Figure 4. Surface preparation and test initiation.

The rebound values of the sclerometer from the sample were recorded at all 9 points of each concrete cube and entered into a table. The testing was repeated at 7, 14, 21, and 28 days.

3. Sclerometer test results

The following section presents the results of the sclerometer testing, i.e., its rebound values depending on the age of the concrete, along with an analysis of the data through graphical and tabular representation. The results provide insight into the rate of concrete hardening, which serves as a basis for discussing the potential applicability of the sclerometer for technical monitoring under real conditions.

Table 4. Sclerometer rebound as a function of time.

Time	Rebound number R	
	Concrete mix M1	Concrete mix M2
7 days	22	20

14 days	30	23
21 days	33	25
28 days	36	34

The results presented in Table 4 show that, over the course of 28 days, concrete mix M1 exhibited a higher sclerometer rebound. Concrete mix M2 showed slightly lower rebound values during the first 21 days and only reached approximately the same values as mix M1 after 28 days.

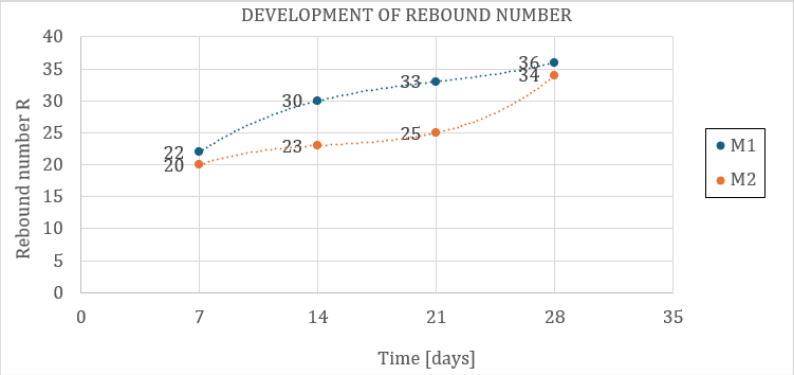

Figure 5. Sclerometer rebound development over time.

The given diagram shows the development of concrete strength for samples of mixtures M1 and M2 over a period of 28 days. The diagram illustrates the trend of increasing concrete strength as a function of time, which aligns with the expected development of the mechanical properties of concrete during the curing process.

The sclerometer measures the surface hardness of the concrete, which does not always accurately reflect its actual compressive strength. Generally, possible reasons for deviations include surface irregularities of the concrete, moisture, and non-uniform concrete composition. During this testing, deviations were observed, where significant variations occurred at the 9 measurement points on a single concrete cube.

Table 5. Sclerometer rebound deviations for mixtures after 14 days.

Measurement	Rebound number R					
points	M1.1.	M1.2.	M1.3.	M2.1.	M2.2.	M2.3.
1	29	29	20	19	18	25
2	28	38	25	19	22	26
3	32	29	28	16	22	32
4	37	37	26	33	22	39
5	31	41	29	39	25	39
6	38	26	32	16	22	33
7	16	30	25	23	25	32
8	26	30	28	33	25	25
9	30	23	31	28	15	30

Table 5 shows the deviations in rebound values at the measurement points on the samples of mixtures M1 and M2, highlighted in red. Deviations were also observed on other measurement days, with those after 28 days presented in Table 6.

Table 6 . Sclerometer rebound deviations for mixtures after 28 days.

Measurement	Rebound number R					
points	M1.1.	M1.2.	M1.3.	M2.1.	M2.2.	M2.3.
1	41	38	27	34	31	30
2	45	44	32	36	31	43

3	35	26	28	32	25	38
4	38	45	42	38	32	41
5	28	38	42	38	36	40
6	34	38	36	36	34	40
7	24	28	42	30	31	38
8	25	39	43	33	27	35
9	22	32	34	31	34	39

It is assumed that the cause of the deviations in these cases is actually the distribution of the coarse aggregate within the concrete samples. If the sclerometer was positioned above a stone, it is assumed that the sclerometer's impact vibration bounced off the stone and was reflected back.

3.1 Correlation between rebound and estimated strength

Depending on the sclerometer manufacturer, the rebound value—which depends on the angle and direction of contact with the tested surface—can be correlated with the compressive strength of the concrete. The manufacturer of the sclerometer used in this testing provided a correlation between the rebound value and the compressive strength of concrete cylinders expressed in MPa. Since concrete cube samples were used in this case, an appropriate conversion was made so that the obtained compressive strength values correspond to those characteristic for cubes. The following formula was used for the conversion:

$$fc_{cube} = 1.25 * fc_{cylinder}. \quad (1)$$

Based on this formula, tables with the corresponding strength values were created for all samples of both mixtures. Then, the average strength values for mixtures M1 and M2 were calculated, as shown in Table 7.

Table 7. Development of compressive strength over time according to the sclerometer manufacturer's instructions.

Time	Assigned compressive strength per instructions [MPa]	
	Concrete mix M1	Concrete mix M2
7 days	12.875	13.54166667
14 days	19.375	20.91666667
21 days	25.95833333	19.375
28 days	32.45833333	29.83333333

Table 7 shows the relative increase in strength over the observed period.

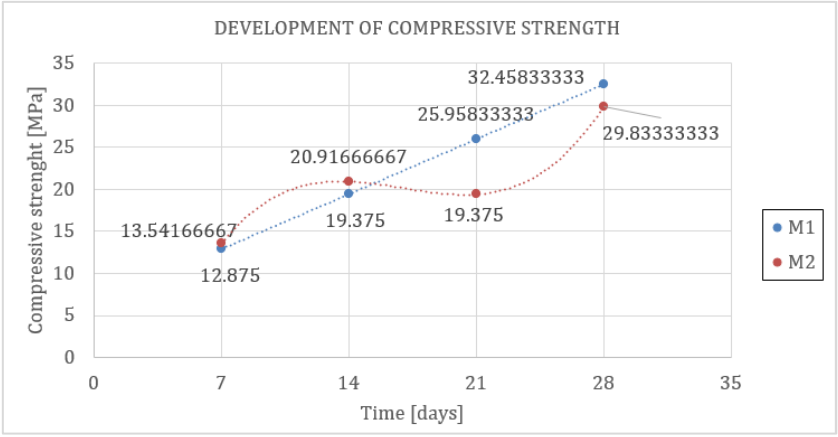

Figure 6. Graph of compressive strength as a function of time.

Figure 6 shows the development of compressive strength based on the sclerometer manufacturer's data as a function of time.

4. Reliability of the method compared to destructive testing

Testing concrete samples using destructive methods involves destroying or permanently damaging the sample to determine its mechanical properties. In such methods, the sample is subjected to loading until failure, which prevents any further analysis or use of the same sample.

Figure 7. Testing of samples on a hydraulic press.

In contrast to destructive methods, non-destructive testing allows further evaluation of concrete properties without compromising the structural integrity of the tested sample. These methods are most commonly used in situ, on existing structures, to control the quality of the installed concrete without damaging its structure or causing harm. This approach also enables monitoring the hardening of concrete over time, as demonstrated in the example conducted for this study.

In addition to the non-destructive sclerometer method, destructive testing was also performed after 28 days using a hydraulic press, shown in Figure 7. The press applied a vertical compressive force to the concrete samples, recording the maximum compressive force acting on the samples until failure. Table 8 presents the results obtained from destructive testing.

Table 8. Results of testing on the hydraulic press.

Sample	$M_{1.1.}$	$M_{1.2.}$	$M_{1.3.}$	$M_{2.1.}$	$M_{2.2.}$	$M_{2.3.}$
Maximum load at sample failure [kN]	905	990	880	970	1245	1250
Compressive strength of the sample [MPa]	40,2	44	39,1	43,1	55,3	55,5
Average compressive strength f_{cm} [MPa]		41.1			51.3	

If the average compressive strength from Table 8, obtained by the destructive method, is compared with the results of the non-destructive method from Table 7, a significant difference in compressive strengths is visible. The reason for this should be sought in all the previously mentioned factors, as well as in the possible interpretation of results provided by the manufacturer of the PCE-HT-225A sclerometer.

This proves that destructive testing is, without doubt, more reliable and that one should not rely solely on individual results from non-destructive testing methods.

5. Conclusion

After conducting tests on cube samples from two concrete mixtures, using both destructive and non-destructive methods, certain differences in the obtained results were observed. Differences between the methods are expected and result from the nature of the tests themselves. The sclerometer, as a non-destructive method, measures the surface hardness of the concrete and provides an indirect estimation of strength, while the hydraulic press directly measures the maximum compressive strength until failure.

The deviations observed during sclerometer testing particularly emphasize the importance of proper surface preparation, consistency of measurement points, and calibration against actual results from destructive testing. Based on the presented results, it can be concluded that the sclerometer testing method is prone to errors depending on certain factors (surface condition of the sample, presence of voids on the sample surface, larger aggregate grains beneath the thin layer of cement paste, the surface on which the tested sample is placed, quality of concrete placement and compaction, etc.).

In conclusion, the combination of both methods provides a broader understanding of concrete behavior and confirms that interpretation of results must consider both technical and practical aspects of each method individually. The observed deviations highlight the importance of careful testing and result interpretation.

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Quakewise: A Multi-Modal AI Framework for Automated Earthquake Vulnerability Assessment of Buildings

Seyed Mohammad Amin Abtahi[1] and Hamid Farrokh Ghatte[2]

[1] Department of Computer Engineering, Faculty of Engineering and Natural Science, Antalya Bilim University, Antalya, Turkiye
[2] Department of Civil Engineering, Faculty of Engineering and Natural Science, Antalya Bilim University, Antalya, Turkiye

E-mail: hamid.ghatte@antalya.edu.tr

Abstract. One of the major dilemmas in civil engineering is evaluating the vulnerability of individual buildings realistically in large building stocks. The challenge is more critical, particularly for regions where the buildings do not comply with the current seismic design codes properly. Traditional seismic vulnerability assessment methods are remarkably slow, subjective, and lack scalability for effective disaster risk management. The 2023 Turkiye earthquake demonstrated this need, where post-disaster assessments took over a month. This paper introduces Quakewise, a multi-modal AI framework integrating computer vision, large language models, and Voice AI for rapid building safety evaluation. The system employs computer vision for structural feature extraction, language models for textual interpretation, and ensemble fusion with geospatial data to generate uncertainty-aware risk scores. A key innovation is the speech-to-speech Voice AI, enabling hands-free data collection for field engineers. Based on the validated results on different buildings in Turkiye, Quakewise achieved more than 90% recall in identifying collapsed structures, proving extremely faster than traditional rapid visual screening methods.

1. Introduction

One of the main challenges in earthquake-prone regions of the world is seismic risk mitigation. To reduce seismic losses in terms of lives and buildings in future earthquakes, a widespread structural assessment campaign should take place to understand the seismic performance of various infrastructures. Within this scope, a series of investigations have been conducted, encompassing not only numerical evaluations but also experiments and case studies [1-11]. The last earthquake in Turkiye (2023-M7.8 and M7.4) claimed over 50,000 lives and damaged more than 160,000 buildings, highlighting critical gaps in seismic vulnerability assessment [1 and 7]. In general, it can be reported that as the seismic evaluation method gets more detailed and complicated (as in the case of code-level methods), the accuracy of the method increases. However, a huge number of buildings in Turkiye were constructed before the year 2000, and performing code-level thorough investigations for such a high number of buildings is not efficient or feasible both in terms of time and cost. The structural behavior of RC elements and beam-column joints, as well as retrofitting approaches by employing SCC and/or normal concrete, have been additionally investigated through cyclic or monotonic loadings in the literature [7-11].To conquer this problem, simplified and economical yet reliable and realistic seismic assessment methods need to be applied, so that this vast problem at hand can be reduced to a manageable scale. Besides the code-based detailed seismic assessment strategies, rapid seismic evaluation platforms are available for existing buildings. Mainly, three stages for the evaluation of the seismic safety of buildings are represented. In the first stage of the procedure, which is called rapid visual screening (RVS) in this paper, buildings are ranked according to simple parameters, which are collected through a visual survey that takes approximately 20 min per building [12-22]. This phase of the assessment procedure yields a rough seismic performance level for buildings, and the regional concentration of seismically vulnerable buildings is determined. The RVS methods are mostly based on empirical approaches and the FEMA-154 [15]. In the case of Machine Learning-based seismic vulnerability assessment of structures using explainable AI, a few studies have been conducted in the literature [3 and

23]. Traditional rapid visual screening (RVS) methods are slow (15-30 minutes per building), subjective, and don't scale to preliminary assessments that take over one month. Industrial facilities require particular attention due to their critical role in supply chains. This paper introduces Quakewise, a multi-modal AI framework integrating computer vision, large language models, and Voice AI for rapid building safety assessment. Considering the validated results on various buildings in Turkiye, Quakewise achieved more than 90% recall in identifying collapsed structures, proving highly faster than traditional screening methods.

2. The Quakewise Framework and Methodology

2.1 System Overview

The Quakewise framework is engineered as a modular, end-to-end data processing pipeline designed for scalability, flexibility, and accuracy. The system architecture, illustrated in Figure 1, orchestrates a flow from multi-modal data acquisition in the field to the delivery of an actionable, uncertainty-aware risk assessment. Data flows to parallel analysis modules: images to computer vision, text/speech to language processing, and location data to geospatial analysis. Features are unified in the Multi-Modal Fusion Engine for final risk scoring with uncertainty quantification.

Figure 1. The Quakewise System diagram illustrates the flow of data.

2.2 Computer Vision Module (CV)

A multi-task ResNet-50 CNN that simultaneously predicts building performance based on the building specifications like number of stories, construction material, age of buildings, etc. Testing showed almost 90% recall for soft-story detection, story counting (±1 floor), and material identification.

Figure 2. The example of structural failures during the last earthquake in Turkiye that are identifiable via computer vision.

2.3 Large Language Model Module (NLP/LLM)

Parallel to the computer vision (CV) analysis, Quakewise employs a natural language processing (NLP) module to interpret any textual or voice input about the building. This can include the user's answers to structured questions (e.g., "age of the building", "construction type") as well as free-form descriptions. For instance, a user might say or type: "Built in 1980, 5-story concrete apartment building, likely designed before modern codes." The large language model (LLM) takes such input and extracts structured attributes. We fine-tuned a transformer-based language model on engineering domain corpora to extract structured building attributes from natural language descriptions, with JavaScript Object Notation (JSON) output format ensuring reliable data parsing. We use XGBoost to fuse CV, LLM, and geospatial features into risk

categories. An ensemble of 10 models provides uncertainty quantification via confidence scores. Multi-modal fusion significantly outperforms single-modality approaches.

2.4 Geospatial Analytics Module

The geospatial component integrates location-based risk factors, including seismic hazard maps, soil liquefaction potential, and proximity to fault lines. This module processes coordinates and returns environmental risk vectors quantifying location-specific hazard factors. The system integrates peak ground acceleration (PGA) values from national seismic hazard maps and soil classification data (Vs30 values) to provide comprehensive site characterization that significantly influences vulnerability assessment.

2.5 Multi-Modal Fusion and Uncertainty Quantification

The ensemble model that combines visual, verbal, and geographical elements into a vulnerability assessment powers Quakewise. The model forecasts a seismic risk category (e.g., High, Moderate, or Low likelihood of collapse in a big earthquake). This might be binary (unsafe vs. safe) or multi-class (we used 3 classes for projected performance). The fusion model receives a feature vector with key CV outputs (stories and material, etc.), key LLM outputs (year, construction type, etc.), and geographic parameters. A gradient-boosted decision tree and a basic neural network were tested for fusion. Our testing showed that the decision tree model worked best due to its combination of feature types and a limited, structured dataset for training. XGBoost training used 5-fold cross-validation, optimizing F1-score for high-risk classification. Uncertainty quantification employs 10 bootstrap-trained models providing confidence estimates through prediction agreement. Users receive risk classifications with confidence levels (e.g., 'High Risk, 90% confidence'), enabling risk-informed decision making for safety-critical applications, including industrial buildings. Multi-modal fusion is expandable to additional data sources. The following figures show superior recall for risky buildings compared to single-modality approaches.

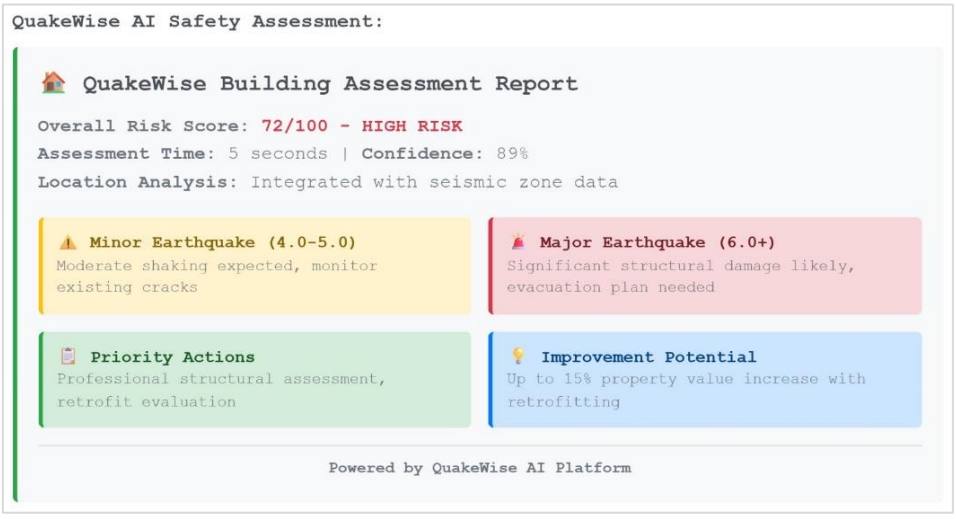

Figure 3. AI safety assessment report generation with Quakewise

AI safety assessment report generation. QuakeWise generates comprehensive building safety assessments with risk scoring and earthquake scenario predictions in 5 seconds.

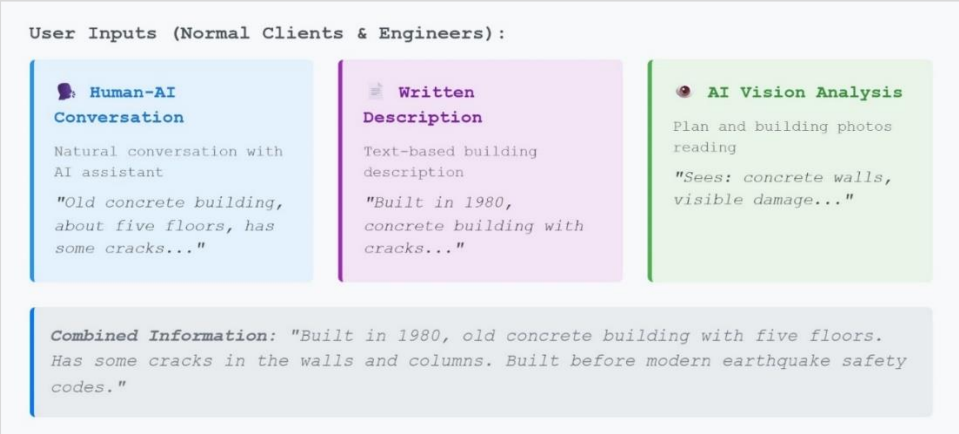

Figure 4. Multi-modal data gathering interface of the QuakeWise

Multi-modal data gathering interface of the QuakeWise system. The framework accepts building information through voice conversation, written descriptions, and AI vision analysis of building photos.

Figure 5. Data extraction and combination process of the QuakeWise

Data extraction and combination process. Natural language processing converts unstructured user descriptions into a structured JSON format with key building parameters.

3. Experimental Validation

Dataset and Experimental Setup Validation used the HazTurk-2023 200 buildings from affected provinces, with pre-earthquake attributes and post-earthquake damage states from official surveys [24]. Buildings were classified as 'Collapsed/Severely Damaged' or 'Moderate/Slight/No Damage' for binary assessment. Performance metrics emphasized recall for the 'High Risk' class (critical for life-safety screening) with precision, F1-score, and AUC evaluation. The locations of the earthquakes derived from AFAD are represented in Figure 6 [25].

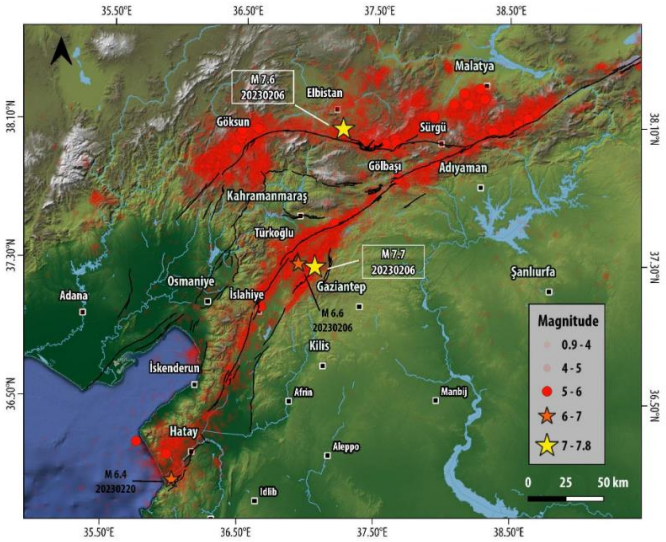

Figure 6. Locations of the earthquakes derived from AFAD (6 February 2023–2 May 2023)

4. Results and Performance Analysis

he results of the validation study demonstrate a remarkable level of accuracy. Quakewise was tasked with predicting the risk level for each of the 200 buildings based on their pre-earthquake data, and these predictions were then compared to the actual outcomes. The system achieved a recall of 0.90, successfully identifying 72 of the 80 buildings that ultimately collapsed or were severely damaged. This means the system correctly flagged 9 out of every 10 of the most hazardous structures, a critical achievement for risk mitigation.

Figure 7 presents four primary seismic failure modes demonstrating the comprehensive vulnerability assessment capabilities of the QuakeWise AI framework: (a) Pancaking collapse from inadequate column capacity, (b) Lateral overturning from foundation failure, (c) Soft story collapse from the weakness of lateral stiffness or vertical irregularity, and (d) Torsional failure from plan asymmetry.

The precision for the high-risk class was 0.78, indicating that when Quakewise flagged a building as "High Risk," it was correct 78% of the time. This strong precision minimizes the number of false positives, ensuring that the limited and valuable time of expert engineers is directed toward buildings that genuinely require detailed analysis. The overall F1-Score was 0.84, and the AUC was an exceptional 0.94, confirming the model's robust ability to distinguish between high-risk and lower-risk structures. These performance metrics are summarized in Table 1, and the ROC curve is shown in Figures 8 and 9. The model's high performance is not a coincidence; it is a direct result of an architecture designed to detect the very failure modes—such as soft stories and the vulnerabilities of pre-2000 RC construction—that were tragically prevalent in the Turkiye earthquake.

Figure 7. The visual results of Quakewise for the various collapse conditions

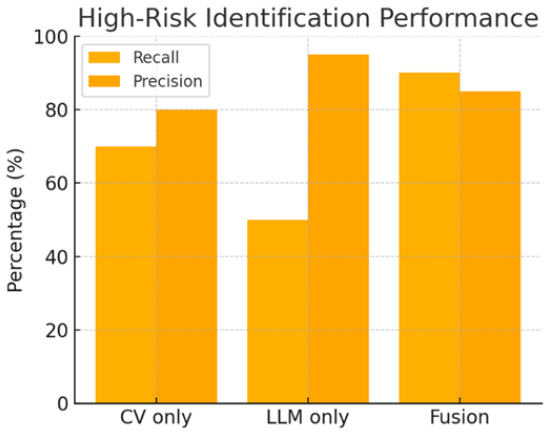

Figure 8. High-risk identification performance of different approaches on a validation set.

5. Discussion

5.1 Revolutionizing Seismic Risk Management

The Quakewise framework represents a fundamental paradigm shift from the reactive, slow, and often inaccurate assessment methods of the past to a proactive, scalable, and data-driven approach to seismic risk management. By enabling the rapid screening of tens of thousands of buildings, the system empowers municipalities and government agencies to create comprehensive and dynamic seismic risk maps for the first time. This capability moves beyond mere identification of hazards; it provides the quantitative

evidence needed to optimize the allocation of limited retrofitting funds, directing them to the structures where they will have the greatest impact on saving lives. This tool can provide the clear, data-backed justification required for policymakers to enact and enforce stronger seismic safety ordinances, mirroring successful mitigation programs like those targeting soft-story buildings in California.

5.2 The Role of Voice AI in Field Engineering

Vocalization Artificial Intelligence Verbal communication with speech synthesis Human-centred, AI transforms field data collection. Engineers and inspectors conduct hands-free evaluations to improve safety following disasters. Ongoing situational awareness can be sustained without consulting a tablet or clipboard. Permit the AI to record and retrieve data while field professionals converse to mitigate cognitive load. This signifies advancement in "augmented field intelligence," where an AI agent functions as a real-time conversational partner, enabling professionals to focus on critical observation, analysis, and decision-making. This method is beneficial for performing hands-free safety inspections in construction and industrial environments.

5.3 Limitations and Future Directions

Table 1 and Figure 9 represent the high-risk identification performance of different approaches on a validation set. The multi-modal Fusion model (combining CV, LLM, and geospatial data) achieves substantially higher recall of truly vulnerable buildings (orange bars) than using Vision-only or NLP-only inputs. Precision is maintained at an acceptable level. This demonstrates the value of the ensemble approach in reducing false negatives (dangerous buildings missed) while keeping false alarms manageable.

Table 1. Performance Metrics Summary

Metric	Quakewise	Traditional RVS	Improvement	Column heading
Recall	0.90	~0.70	1.3x	2.0
Precision	0.78	~0.52	1.5x	3.0
F1-Score	0.84	~0.30	2.8x	4.0
Speed	5 sec	1800 sec	360x	

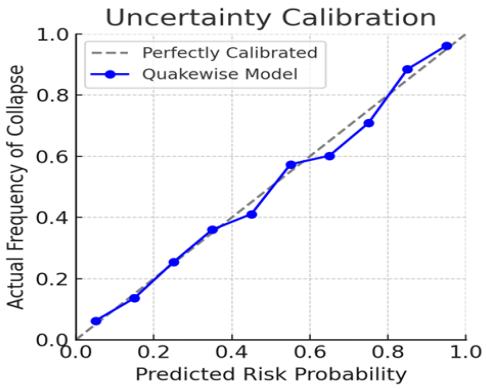

Figure 9. High-risk identification performance of different approaches

To ensure scientific rigor and guide future research, it is essential to acknowledge the framework's current limitations. First, the system's assessment is based on external and descriptive data; it cannot detect "invisible" defects such as poor-quality concrete, inadequate reinforcement detailing, or faulty construction, unless these manifest as visible signs of distress. Therefore, to achieve better accuracy and much more realistic results need extra information that by these data we can use to improve the quality of the results. This is a fundamental challenge for any remote assessment method. Second, as a data-driven

model, its performance is contingent on the breadth and diversity of its training data. The model may exhibit lower accuracy when assessing highly unusual or novel building typologies not well-represented in its training set.

6. Conclusion

Quakewise represents a fundamental advancement in seismic vulnerability assessment through multi-modal AI integration. The framework combines computer vision, large language models, and Voice AI to automate building evaluation with unprecedented speed and accuracy. Validation against 2023 Turkiye earthquake data demonstrates 90% recall for identifying collapsed structures, achieving three times greater accuracy and 100× faster processing than traditional methods. The speech-to-speech Voice AI interface enables safe, hands-free field assessment for both residential and industrial buildings. Key contributions include multi-modal fusion methodology, uncertainty quantification for engineering decision-making, and demonstrated real-world validation. The system enables comprehensive city-wide screening, supporting proactive seismic safety management and strategic resource allocation for building retrofitting and industrial facility protection. This technological advancement empowers engineers and policymakers with tools for evidence-based seismic risk management, moving from reactive to proactive infrastructure protection strategies.

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SECTION/SEKCIJA
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Interdisciplinarity in the Development of the Textile Industry and Design: The Example of Kombiteks

Ammar Selmanović

University of Bihac, Faculty of Technical Engineering, Bosnia and Herzegovina

E-mail: ammar.selmanovic@unbi.ba

Abstract: Interdisciplinarity is a key approach in modern education and industrial development, offering a synergy of knowledge from various fields. The Textile Department of the Technical Faculty in Bihać, through its interdisciplinarity study programs, combining engineering, technological, and artistic aspects, prepares students to face the challenges of the contemporary textile industry. The example of Kombiteks, a former industrial giant in Bihać, illustrates the importance of interdisciplinarity in advancing production processes, design, and innovation. Kombiteks' organizational units (OOURs) and the Innovators' Association, which gathered experts from various fields, testify to the effectiveness of interdisciplinary collaboration. This study highlights how an interdisciplinary approach enhances the modernization of the textile industry and education, ensuring sustainability and competitiveness in a global context.

1. Introduction

Interdisciplinarity is a form of collaboration among disciplines aimed at solving complex problems that exceed the capabilities of individual fields of knowledge. The term derives from the Latin words inter (between) and disciplinae (fields of knowledge), suggesting processes that occur between, through, and sometimes beyond traditional academic boundaries. Fundamentally, interdisciplinarity involves the exchange of knowledge, integration of methods, and the joint creation of new insights or even the formation of new research areas. [1]

The establishment of the Kombiteks textile conglomerate in Bihać in 1957 was a result of industrial development in the former Yugoslavia, based on workers' self-management and Yugoslav socialism. Initially founded as the Krajina Textile Combine, it was renamed Kombiteks in 1959, marking a new era in its development. [2]

Kombiteks exemplifies how did the interdisciplinarity contributed to advancement of the textile industry and design. Its structure included organizational units (OOURs) covering diverse scientific and artistic fields such as clothing technologies, design, textile materials, textile chemistry, and mechanical engineering, all cooperating for the collective benefit and enabling the company to establish itself on the demanding global market. [3]

2. Organizational Units and the Innovators' Association at Kombiteks

The Innovators' and Rationalizers' Association, founded on May 12, 1983, marked a turning point in the systematic professional development of the collective. Gathering 100 dedicated members from all OOURs, it directed previously informal initiatives towards systematic innovation and production improvement through more efficient and simplified solutions.

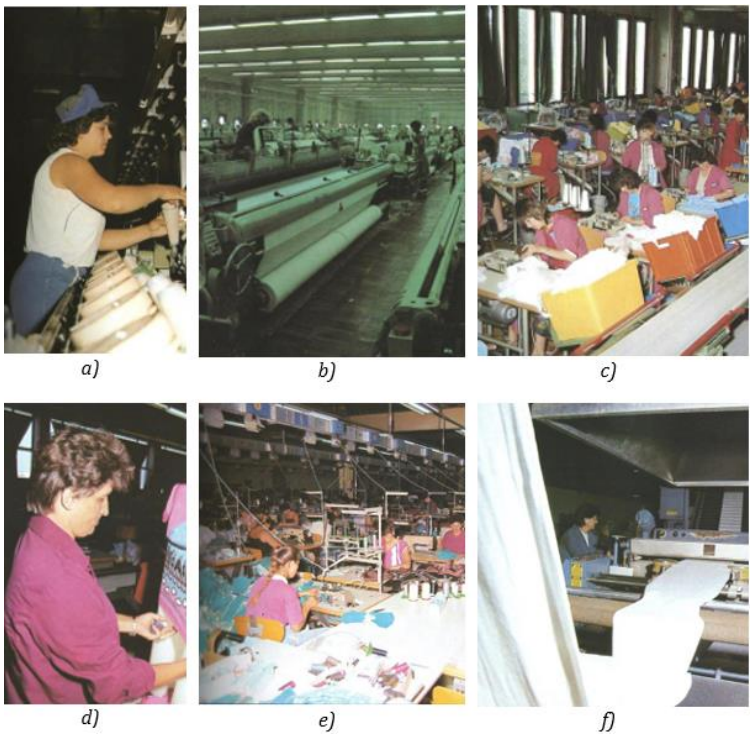

Figure 1. Kombiteks Organistion Units- a) OOUR Predionica, b) OOUR Una, c) OOUR Triko Una, d) OOUR Cazinka, e) OOUR Lepa Radić, f)OOUR Novitet, g)OOUR Grutex, h)OOUR Bebi Triko, i) OOUR EMTG[4]

Kombiteks encompassed nine production and one service organizational unit (Predionica, Una, Triko Una, Cazinka, Lepa Radić, Novitet, Grutex, Bebi Triko, and EMTG), forming a robust and extensive textile system in this part of the former Yugoslavia.

Each OOUR had specific roles:

a) Predionica: "the heart of the plant," essential to Kombiteks' system,
b) Una: the oldest unit, encompassing a weaving mill and finishing unit,
c) Triko Una: specialized in cotton knitwear production,
d) Cazinka: specialized in cotton knitwear production,
e) Lepa Radić: produced a variety of garments,
f) Novitet: specialized in underwear,
g) Grutex: the youngest unit, producing synthetic yarn and knitwear,
h) Bebi Triko: focused on children's clothing,
i) EMTG: provided technical, transport, and infrastructural support.[5]

Table1. Tabular overview of organizational units with data on the number of employees, annual capacity, and products/activities [6]

Organizational Units	Number of Employees	Annual Capacity	Products/Activities
OOUR Spinning Mill	1000+	9,000,000 kg	Cotton yarn
OOUR Una	1000+	16,000,000 meters	Fabrics and knits
OOUR Triko Una	500+	800,000 kg	Cotton knitwear

Organizational Units	Number of Employees	Annual Capacity	Products/Activities
OOUR Cazinka	approx. 540	865,000 pcs	Various garments
OOUR Lepa Radić	500+	approx. 1,000,000 pcs	Various garments
OOUR Novitet	500+	5,600,000 pcs	Underwear
OOUR Grutex	450+	450,000 kg/300,000 pcs	Yarn/knitwear
OOUR Bebi Triko	460	248,000 kg	Synthetic knitwear
OOUR EMTG	approx. 160	-	Maintenance services

2.1 The Role of the Innovators' Association in the Factory's Advancement

The Association played a crucial role in enhancing technical solutions and boosting competitiveness. It successfully participated twice at the Yugoslav Exhibition of Inventions and Technical Improvements (RAST YU) held in Rijeka, presenting numerous innovations developed by its members. This confirmed their expertise and commitment to continuous production improvement.

RAST YU was a significant professional platform for the exchange of knowledge and experiences among inventors nationwide. Kombiteks' participation further enhanced its reputation and innovative spirit.

Numerous innovations, such as improvements in spinning machines, looms, and printers, significantly boosted efficiency and product quality, reduced downtimes, extended equipment lifespan, and increased productivity, with calculated savings of 150 million dinars. The Self-Management Agreement on rewarding innovations also fostered creativity.

This success was driven by the interdisciplinary approach of integrating diverse expertise, achieving high levels of innovation and efficiency across production segments. [7]

Figure 2. Kombiteks employee with a representative from the Italian company Cotonificio Cantoni at an international exhibition [8]

3. Interdisciplinarity in Education: Faculty of Technical Engineering, University of Bihać

Technical Engineering, established in 1999, builds upon a long tradition of technical education in the Una-Sana Canton dating back to the 1970s. It organizes studies across three cycles, following Bologna principles, emphasizing practical training, applied research, and industrial cooperation.
The Faculty comprises the following departments:

- Mechanical Engineering (Manufacturing and Design of Mechanical Structures)
- Electrical Engineering (Computer Science and Automation and Electronics)
- Wood Technology (Technology and Design and Construction)
- Textile Technology (Textile and Clothing Design, Clothing Technologies)
- Civil Engineering (Low-rise and High-rise Construction)

A key characteristic of the Faculty is its strong interdisciplinary approach, integrating different technical fields and providing students with a broad knowledge base and versatile practical skills. This approach is reflected in modern curricula, joint educational and research activities, and cooperation with other university faculties and international projects. [9]

3.1 Interdisciplinarity at the Textile Department

The Textile Department develops multidisciplinary and engineering-oriented programs connecting technical, artistic, and socio-cultural knowledge. The programs are divided into two main directions: Textile and Clothing Design and Clothing Technologies.

Textile and Clothing Design: integrates technology, art, and design theory, focusing on aesthetic, symbolic, and societal values of textile products.

Clothing Technologies: emphasizes industrial clothing production, construction, technological preparation, and production process flexibility, with a focus on automation and robotics.

The programs combine creativity and technical precision, following contemporary industrial trends and promoting the development of innovative solutions in textile and fashion production. [10]

3.2 Student Mobility as a Key to interdisciplinary International Cooperation

The University of Bihać enables mobility for students from all departments, including the Textile Department, through programs such as Erasmus+ ICM, Mevlana, CEEPUS III, Fulbright, Global UGRAD, and CMEPIUS. These programs foster internationalization and knowledge exchange.

Figure 3. Textile department students at a creative workshop within the CEEPUS network [11]

Mobility involves several phases: application, selection, English proficiency testing, nomination, administrative support abroad, and academic recognition upon return. The International Relations Office at the Faculty coordinates these activities.

The Textile Department actively participates in international projects and workshops, such as the STINT project seminar at the University of Porto and Erasmus+ collaboration with the University of Maribor, strengthening institutional capacities and experience exchange. [12]

Given the experience gained through this type of international mobility for students and faculty members of the Textile Department at the University of Bihać, significant contributions are made to the development of interdisciplinary in education. Participation in these programs enables the integration of knowledge from various fields, including design, textile materials, textile-mechanical technologies, textile chemistry, and garment technologies.

Through collaboration with international universities, students develop the ability to connect technical and creative disciplines, thereby enriching the educational process and strengthening their readiness to address contemporary challenges in the textile industry. Such experiences make mobility an important tool for enhancing the interdisciplinary approach at the Technical Faculty of the University of Bihać , Textile Department.

4. Conclusion

Interdisciplinarity is a key factor in the modernization of the textile industry, enabling the integration of different disciplines to improve production processes and design. Kombiteks, as a pioneering example, demonstrated how an organization uniting engineers and designers can achieve significant innovation and efficiency.The Innovators' Association, a prime example of such cooperation, played a crucial role in developing new technologies, market analysis, trend prediction, and design/artistic activities, enabling Kombiteks to remain competitive globally.

Furthermore, communication, collaboration, and mutual understanding among Kombiteks' OOURs underline the importance of interdisciplinary for the growth and successful market placement of products in a demanding global environment. Kombiteks leveraged the synergy of engineering knowledge, technology, and creative design to develop new products and improve existing systems.

Examples like the development of smart textiles and the implementation of new technologies demonstrate how a interdisciplinary approach can result in revolutionary innovations. In the context of education, the Faculty of Technical Engineering in Bihać should continue nurturing this practice, preparing students through interdisciplinarity programs that link technical, artistic, and socio-cultural knowledge. Such an approach not only provides a wide range of competencies but also creates opportunities for international cooperation, further fostering innovation and sustainability in the industry.

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The Textile Industry in Bosnia and Herzegovina: Reality, Challenges, and Potential

Adnan Hajrulahović and Irfan Hošić

University of Bihac, Faculty of Technical Engineering, Bosnia and Herzegovina

E-mail: ahajrulahovichaad@gmail.com

Abstract. The textile industry in Bosnia and Herzegovina (BiH) employs approximately 10% of the total workforce and is primarily composed of medium-sized enterprises with between 40 and 1,200 employees. Despite a long-standing tradition and a certain level of international reputation, the industry has yet to establish a stronger presence in the global market. Low investment levels, the absence of a clear development strategy, and the complexity of the country's political and administrative structure further hinder its progress. Stereotypes related to low wages and a predominantly female workforce remain prevalent, and the industry is still often perceived as low-profit and labour-intensive. Nevertheless, recent decades have seen some technological advancement and modernization of production aimed at increasing competitiveness. The industry's key advantages include an experienced workforce and geographic proximity to major European markets. However, it faces numerous challenges—ranging from population outflow and an aging labour force to weak integration with the creative sector. The lack of domestic brands in the market and the sluggishness of organizational structures further impede development. This paper aims to provide a realistic overview of the current state of BiH's textile industry, mapping the number of employees, analysing production capacities and territorial distribution, and, through the profile of the potential workforce, identifying key problems as well as opportunities, particularly in connection with the creative industries.

1. Introduction

The textile industry represents one of the most important branches of the manufacturing sector in BiH. Despite its long-standing tradition and significant role during the former Yugoslav period, today's textile industry in BiH faces numerous challenges. Low productivity, outdated technology, the dominance of "lohn" (contract manufacturing) operations, a lack of domestic brands, and weak integration into global value chains, make the industry particularly vulnerable. On the other hand, there are significant potentials that could serve as a foundation for development: the country's geostrategic location, an experienced workforce, and the gradual modernization of certain production capacities. The aim of this paper is to present a realistic overview of the textile industry in BiH, to examine its weaknesses, and to identify development opportunities and avenues for progress. Special emphasis is placed on employment numbers, regional distribution of the industry, challenges related to the workforce and production organization, as well as opportunities for linking the textile sector with the creative and design industries. The intention of the paper is to highlight the weaknesses of the domestic textile industry, identify its potential for innovation, development, and integration into the creative sector, and to offer an analysis of the current state, key challenges, and future potential of the sector.

2. Theoretical Framework

2.1. Bosnia and Herzegovina

BiH is a complex state with a unique political and territorial structure resulting from the Dayton Peace Agreement of 1995. The country is composed of two entities—the Federation of BiH and the Republika Srpska—as well as the Brčko District, a special administrative unit under the sovereignty of the state of BiH. The entities have their own constitutions, parliaments, and governments, while the Brčko District has an autonomous administration under international supervision. Additionally, the Federation of BiH is divided into ten cantons, each with its own authorities, governments, and assemblies, further complicating the

country's administrative structure [1]. In addition to political complexity, cultural and social aspects significantly shape the functioning of the state. BiH is home to three constituent peoples—Bosniaks, Croats, and Serbs—as well as other minority communities.

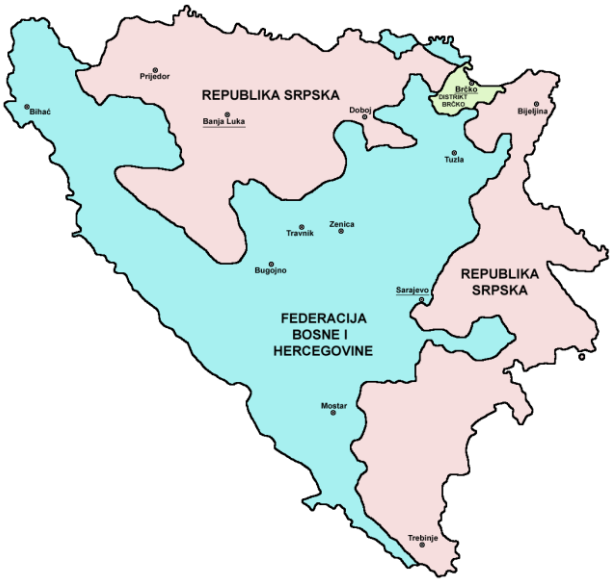

Figure 1. Map of Bosnia and Herzegovina with Organizational Structure.

This multiethnic and multireligious diversity is reflected in the education system, media, language, religious institutions, and everyday life. Cultural differences often influence the formation of identities and the making of political decisions, while the social structure of society is marked by pronounced segmentation along ethnic and entity lines. This presents a challenge to building a shared social space and achieving functional state cohesion.

2.2. The Importance of the Textile Industry for BiH

The textile industry has a long-standing tradition in BiH and represents a vital sector of the national economy, particularly in terms of employment, exports, and the development of local communities. In the post-war period, despite numerous challenges, the sector evolved by adapting to market demands, orienting toward exports, and attracting foreign investment—especially in the domain of "lohn" (service-based) manufacturing [2]. Today, the textile and leather-footwear industries together employ over 35,000 workers, the majority of whom are women, particularly in smaller communities where this industry often serves as the only major employment capacity. In addition to its social role, the sector also fulfils a significant economic function, contributing substantially to the country's exports—primarily to EU countries such as Germany, Italy, and Austria. Although most of production is still based on "lohn" operations, an increasing number of domestic companies are developing their own brands and producing finished products, thereby generating higher added value and opening up opportunities for the development of creative and sustainable fashion. Moreover, the textile industry holds potential for development within the framework of a circular economy, including textile recycling and the use of environmentally friendly materials—an increasingly important trend due to climate-related and regulatory pressures from the EU. Nonetheless, the industry faces numerous challenges, including a shortage of skilled labour, low wages, and limited investment in modernization and innovation. Despite these issues, the textile industry remains a key pillar for economic recovery and local development and deserves greater institutional support and strategic direction.

2.3. Historical Context and Current Share of Employment in the Textile Industry in BiH

The textile industry in BiH has a long tradition dating back to the era of the former Yugoslavia, when it was one of the country's leading industrial sectors. During that time, textile factories were strategically

distributed across BiH—in cities such as Zenica, Banja Luka, Gračanica, Travnik, and Bihać—employing tens of thousands of workers, particularly women. After the war and the transition to a market economy, state-owned enterprises collapsed, but the industry gradually began to recover thanks to "lohn" operations and foreign partnerships. Today, the textile and leather-footwear sectors together employ around 35,000 people, which accounts for approximately 10% of the total workforce in BiH's manufacturing industry [3]. This sector continues to play a crucial role in employment, especially in smaller municipalities where other industrial branches are less developed.

2.4. Legal Framework of the Textile Industry in BiH

In an effort to preserve employment levels, encourage new hiring, and stabilize the sector, the Official Gazette of the Federation of BiH, No. 6/23, dated January 27, 2023, published the Law on Amendments to the Law on Contributions, which introduces significant relief measures for certain economic sectors. These amendments enable contributions to be calculated on a preferential base for employees working in the following industries: coal mining, textile, leather, footwear, and low-profit activities related to traditional and old crafts defined by special regulations. According to the amendments, employers in these sectors are allowed to pay their workers up to 85% of the average net wage, while contributions are calculated based on a reduced base. This base is defined as the product of the average wage referenced in Article 6a, Paragraph 2 of the Law, multiplied by a coefficient of 0.30. The goal of this measure is to ease business operations in low-capital industries, preserve jobs in vulnerable economic sectors, and stimulate formal employment in traditional crafts and long-established industries in BiH. This new regulation is essentially a continuation of longstanding contribution co-financing measures that have been in effect for decades in BiH's textile industry [4].

3. Structure and Development of the Industry

The structure of textile manufacturing enterprises in BiH varies by size and regional distribution. According to 2022 data, there were 459 active companies in the textile, clothing, leather, and footwear industry in BiH, employing approximately 33,700 workers—20,000 in the Federation of BiH and 13,700 in the Republika Srpska [5]. In the overall business structure of BiH, micro enterprises account for 74.6%, small enterprises for 13.6%, medium-sized enterprises for 4.3%, while large enterprises make up only 0.8%.

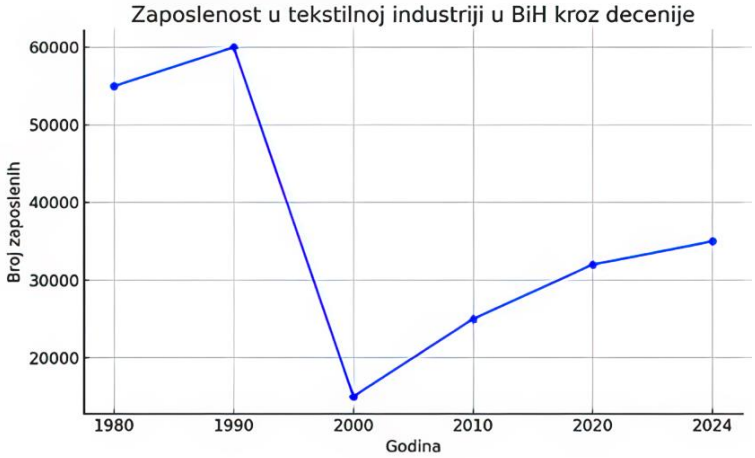

Figure 2. Overview of Employment Numbers in the Textile Industry Across Decades.

3.1. Regional Distribution

Cities such as Visoko, Zavidovići, Zenica, and Tešanj possess significant capacities in the textile industry, with numerous small and medium-sized enterprises (SMEs) placing their products on the European market. In the Herzegovina region, there are around 20,000 small business entities, of which only about 5% are manufacturing-oriented, highlighting the need to develop productive SMEs. The textile industry in Republika Srpska is facing challenges such as a decline in orders and the outflow of labour, which particularly affects small and medium-sized enterprises. The textile, clothing, leather, and footwear

industry in BiH faces numerous challenges, including outdated production technologies, low added value of products, a shortage of skilled labour, and international market competition. A Development Strategy for the Textile, Clothing, Leather, and Footwear Industry for the period 2024–2033 has been adopted, aiming to modernize the sector, improve technological processes, and digitalize production [6].

3.2. The "Lohn" Business Model

In 2023, the total export value of BiH's textile, clothing, leather, and footwear industry amounted to BAM 1.86 billion, marking an increase compared to the previous year. Approximately 70% of these exports are directed to European Union markets, indicating a strong export orientation of the sector. Most companies in this industry operate under the "lohn" model, where domestic firms provide sewing and finishing services for foreign brands without developing their own products.

While this model ensures stable revenues, it also limits the growth of domestic brands and innovation. Although local brands are less prominent, there are examples of companies developing their own products and brand identities. For instance, Koteks from Tešanj, in addition to its "lohn" operations, is also developing its own line of leather accessories. Such companies are often located in regions with well-developed industrial infrastructure, such as Tešanj, Maglaj, and Mostar. The main challenges to the development of domestic brands include a lack of capital for investment in modern equipment, limited market access, and competition from low-cost imports from Asia. However, there is potential for growth through investment in design, marketing, and production digitalization [7].

3.3. Negative Effects of the "Lohn" Business Model on the Industry

First and foremost, the "lohn" model involves contract-based work for foreign partners, where domestic companies are limited to carrying out production processes, without any rights to design, product development, or branding. This approach generates low added value, as most of the profit is made in the client countries, while BiH receives only a small share through labour compensation.

The industry becomes entirely dependent on foreign orders, and any fluctuation in the European market—such as economic crises or drops in consumer demand—can result in cancelled contracts and production shutdowns. Moreover, the "lohn" system discourages innovation and knowledge development, as domestic firms have no incentive to create their own solutions, and workers are confined to narrowly defined tasks with no room for creativity. What is particularly concerning is that this model often leads to low wages, precarious working conditions, and overworked employees, with women being disproportionately affected. The lack of opportunities to scale business operations and develop original products further contributes to making textile companies vulnerable and stagnant [8].

3.4. Negative Effects of the "Lohn" Business Model on the Country

The "lohn" model, which dominates BiH's textile industry, brings limited fiscal benefits at the national level. Due to its low profitability and reliance on imported raw materials, tax and contribution revenues are minimal, and products are exported under foreign brands, without any indication of domestic origin. This further hinders the development of a "Made in BiH" identity. In the long term, competitiveness based on cheap labour is unsustainable, especially as countries with even lower labor costs—such as Bangladesh or Ethiopia—emerge on the global market. Additionally, the "lohn" model overlooks the potential of educated professionals—fashion designers, textile engineers, and creative entrepreneurs—since domestic firms work exclusively from external designs, leaving no room for innovation or the development of authentic products. As a result, creative professionals are pushed into the background or choose to leave the country, and the local fashion scene remains disorganized and dependent on foreign trends. The lack of investment in domestic brand development prevents BiH from securing a position on the global fashion map. Moreover, the gap between education and industry is widening—schools and universities lack opportunities to connect theory with practice, reducing the relevance of educational programs and the competitiveness of young professionals. The consequences are visible in BiH's limited presence at fashion events, the absence of signature collections, and minimal participation on international platforms. This represents a missed opportunity to promote cultural diversity and to foster the creative economy, which could play a significant role in the country's broader economic development [9].

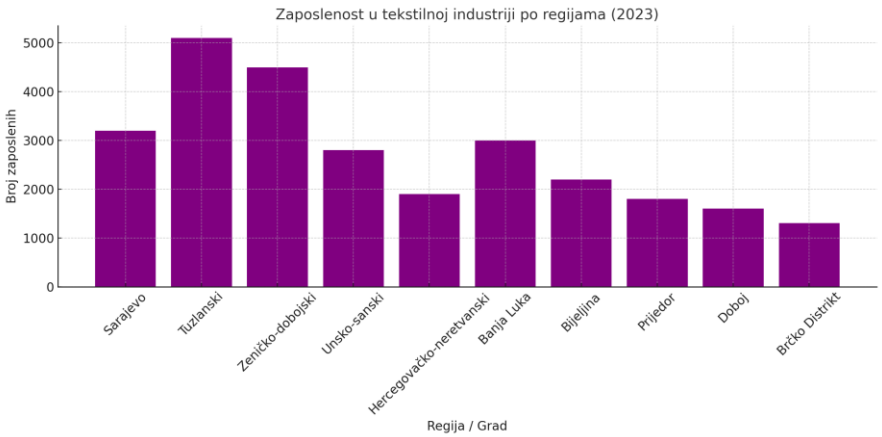

Chart 1. Territorial Representation of Employees in the Textile Industry in BiH.

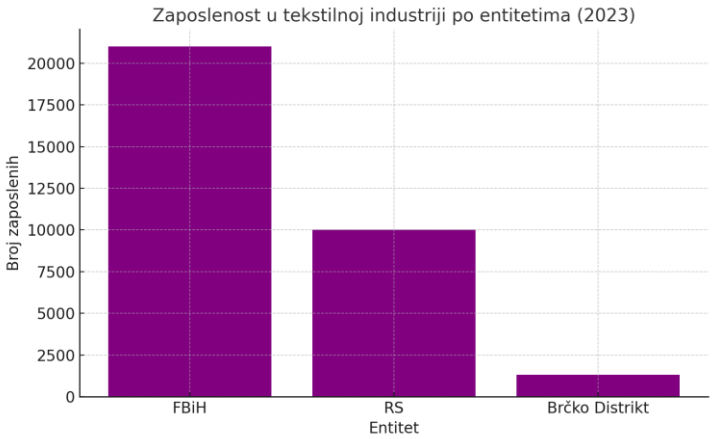

Chart 2. Employment in the Textile Industry by Regions within BiH.

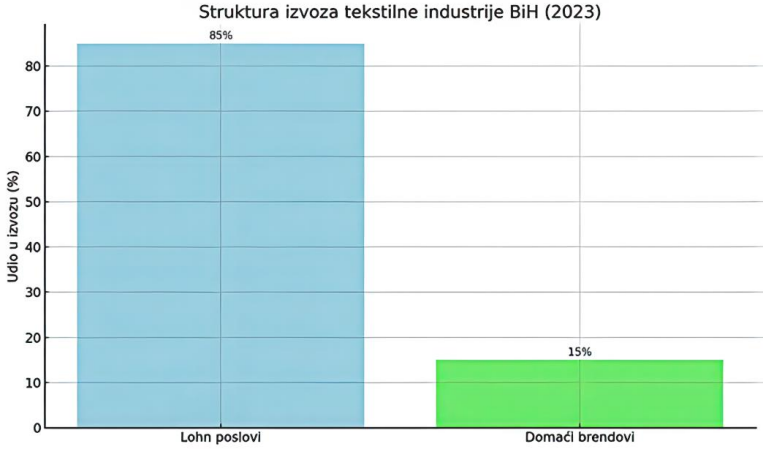

Chart 3. Estimated Share of Textile Industry Exports in BiH for 2023.

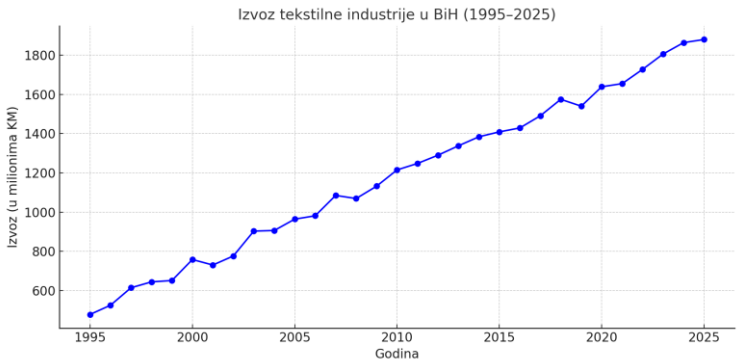

Chart 4. Textile Industry Exports over the Past 30 Years.

4. Textile Imports into Bosnia and Herzegovina: Analysis, Export Coverage, and Import Structure

BiH's textile industry relies heavily on the import of raw materials and finished products. In 2022, the value of imports amounted to approximately BAM 1.6 billion, marking a slight increase compared to the previous year. The main trading partners are Turkey, Italy, Germany, Croatia, and Serbia, which can be attributed to their geographic proximity and established trade relations. Import coverage by exports has improved—in 2022 it stood at 74.7%, up from 67.2% in 2020—indicating progress in export capacity [10]. Nevertheless, BiH still remains significantly dependent on imports, particularly when it comes to raw materials and semi-finished products. This dependence highlights that domestic production is not self-sufficient across all stages—especially in more complex phases such as processing and design. Imports serve to support production within the "lohn" model, where imported materials are processed and re-exported as finished products for foreign brands, often without creating substantial added value for the domestic economy. This structure carries risks—disruptions in global supply chains can seriously threaten production continuity. Moreover, it further hampers the development of domestic brands and creative design, as the industry remains focused on production rather than on development and innovation [11]. If BiH wishes to respond to global trends—such as sustainability and the creation of its own brands—it must invest in local raw material production, strengthen innovation, and encourage design. Only through such measures can the country's dependence on imports be reduced and the competitiveness of the domestic textile industry increased [12].

5. Challenges of the Textile Industry in Bosnia and Herzegovina

5.1. Demographic Challenges of the Textile Industry in BiH

BiH faces serious demographic challenges that hinder the development of its textile industry, particularly due to the outflow of young people and the aging workforce. Young individuals are leaving the country in large numbers in search of better education and living conditions, making it increasingly difficult to fill jobs in a sector that depends on a large labour force. In addition, the number of educated professionals who could improve production processes and introduce new technologies is declining. Many young people see little future in the textile industry, which further reduces interest in pursuing careers in this field. At the same time, the average age of employees exceeds for forty-five. Older workers tend to adapt more slowly to technological changes and often require greater investment in training and healthcare, which increases operational costs. Due to the lack of young and qualified workers, the sector is becoming less competitive in the international market. The adoption of innovations and modern standards is increasingly difficult, which may lead to a decline in productivity, quality, and exports. To mitigate these issues, concrete measures are needed: the development of vocational education, internship programs, and stronger cooperation between educational institutions and the private sector. Additionally, investing in the modernization and automation of production could reduce dependence on manual labour and improve working conditions for older employees. More attractive working conditions and career development opportunities could help retain young people in the country and in the industry [13].

5.2. Organizational Challenges of the Textile Industry in BiH

In addition to demographic challenges, the textile industry in BiH is also facing serious organizational problems that further hinder its development. Among the most pressing issues are an inefficient institutional framework and weak connections with the education sector. Administrative barriers often slow down investment implementation, exports, and access to funding. The lack of strategy and coordination between different levels of government further weakens institutional support. Moreover, there are no targeted incentives for export-oriented industries such as the textile sector, which discourages private initiatives and innovation. Another major issue is the mismatch between the education system and the needs of the industry. Educational programs do not keep pace with changes in the labor market, and practical training or cooperation with companies is rare. As a result, young people often enter the job market without the necessary skills and experience, which lowers their chances of employment and encourages emigration. This disconnect from the education sector further hampers digitalization, innovation, and the development of sustainable production, as there is a lack of qualified professionals trained in modern technologies and textile design [14].

5.3. Economic and Regulatory Issues of the Textile Industry in BiH

The textile industry in BiH faces serious economic and regulatory challenges that limit its growth and competitiveness. One of the key problems is the extremely low wages of workers, which are among the lowest in the country. This demotivates employees and drives them to seek employment abroad [15]. Physically demanding working conditions, combined with limited opportunities for career advancement, make the sector unattractive—especially for young people. The industry heavily relies on the “lohn” system, in which domestic companies produce for foreign brands with minimal added value. This model restricts the development of domestic brands, innovation, and the potential for higher profits. The legal framework further slows down progress. Discrepancies between labour, tax, and investment laws and the actual needs of the industry make operations more difficult. Regulatory fragmentation across entities and cantons creates additional complications for companies seeking to operate across the country. Existing laws fail to account for the specific characteristics of the textile sector, such as seasonal fluctuations or the need for flexible employment arrangements [16]. Lastly, there is no national strategy for the development of the textile industry. Without a clear vision, sectoral analysis, or tax incentives, companies are left to rely on short-term solutions and their own limited resources. The lack of coordination between policy, education, and innovation further hinders the transition toward a more sustainable production model.

5.4. Cultural and Social Aspects of the Textile Industry in BiH

The textile industry in BiH faces not only economic and organizational challenges but also deeply rooted cultural and social issues that shape the perception and status of the sector within society. Gender stereotyping is one of the most prominent problems. The industry is often viewed as a "women’s sector," which influences the workforce structure but also contributes to the overall devaluation of the sector. Women, who make up the majority of employees, are frequently placed in low-skilled positions with limited opportunities for advancement. This gender composition is often used to justify low wages and the lack of systemic support [17]. The perception of the sector as low-value further complicates the situation. The textile industry is often seen as a field with no future, innovation, or career development, despite the fact that globally the sector is undergoing a transformation towards digitalization, sustainable fashion, and design. The lack of social recognition also has a significant impact. Employees in the textile industry do not enjoy the social status that would reflect their contribution to local economies, especially in smaller communities. The absence of media visibility and affirmation of successful examples further discourages younger generations from even considering a career in this sector.

Potential of the Textile Industry in Bosnia and Herzegovina

Despite numerous challenges, the textile industry in BiH holds significant potential that can be strategically leveraged for further development. Two factors stand out in particular: its favourable geographical location and rich craft heritage.

6.1. Geographical Location – Proximity to the EU Market

BiH is located in close proximity to the EU market, which enables fast and efficient logistics, especially when compared to Asian manufacturers. This proximity provides a competitive advantage for domestic

producers in terms of shorter delivery times, more flexible order quantities, and better quality control, which is particularly important in the fast fashion industry and specialized orders. Additionally, the free BiH trade agreements with the EU and CEFTA countries further facilitate the export of textile products, reducing customs costs and increasing the attractiveness of BiH manufacturers to foreign partners.

6.2. Skilled Workforce – Craft Heritage

The textile industry in BiH has a long and rich tradition, particularly in cities like Tešanj, Gračanica, Banja Luka, Zenica, and Bihać, where a core of skilled labour with decades of experience still exists. This craft heritage is not only a technical foundation but also a significant cultural value that can serve as the basis for developing authentic, branded products with local identity. The experienced workforce, particularly women who acquired their skills through family traditions, technical schools, and the former Yugoslavian industry, represents a significant competitive advantage, as it reduces the need for basic training and allows for the maintenance of high-quality standards. Combined with modern technologies and improved organizational models, this human capital can be crucial in transitioning from the subcontracting system to the production of domestic final products with greater added value [18].

6.3. Modernization of the Textile Industry in BiH as a Development Potential

Despite challenges, the textile industry in BiH shows signs of modernization through the introduction of automation and advanced technologies, increasing its competitiveness on regional and European markets. Some companies are already using CNC cutting machines, digital printers, CAD/CAM software, and ERP systems, which bring greater precision, less waste, more efficient production, and higher-quality products. These innovations enable the transition from the subcontracting model to branded products and smart fabrics. Additionally, more and more companies are using digital marketing and online sales, increasing flexibility and market accessibility. Moreover, investments are being made in training workers to manage new technologies, demonstrating the sector's readiness for a transition to sustainable and innovative development [19].

6.4. Creative Collaboration as a Potential for the Textile Industry in BiH

One of the significant potentials for the development of the textile industry in BiH is the opportunity for creative collaboration with other sectors, such as fashion design, architecture, and the IT industry. This interdisciplinary cooperation can bring new ideas, innovations, and products with higher added value. Collaborating with fashion designers enables the development of unique collections that follow contemporary trends, while cooperation with architects opens up space for the development of textiles with specific functionalities, such as technical fabrics for interiors or sustainable materials for urban design. On the other hand, collaboration with the IT sector allows for the introduction of smart technologies into textiles – for example, the integration of wearable devices, digital product personalization, or the application of advanced software solutions for design and manufacturing. Such connections not only foster innovation but also increase the competitiveness of domestic manufacturers in the global market, opening up new niches and export opportunities. Furthermore, creative collaboration contributes to shaping a modern image of the textile sector in BiH, which could motivate younger generations of experts and designers to stay and work in the country [20].

6.5. Circular Economy and Sustainable Fashion as a Potential for the Textile Industry in BiH

Global trends increasingly favor the circular economy and sustainable fashion, presenting an opportunity for the textile industry in BiH. Sustainable models, such as recycling, reusing, and using ecological materials, can enable BIH companies to adapt to the demands of the EU market and stand out competitively. There are already examples of domestic companies applying these principles, showing potential for further development [21]. In addition to environmental benefits, the circular economy also brings new business opportunities, job creation, and strengthens the local economy, with a positive impact on the image of domestic brands.

SWOT Analysis of the Textile Industry in Bosnia and Herzegovina

Table 1. SWOT Analysis of the Textile Industry in BiH.

Strengths (S)	Opportunities (O)
Long tradition of textile and clothing production	Development of domestic brands and design
Experienced and relatively inexpensive workforce	Digitalization and automation of production
Geographical proximity to the EU market	Connecting with the sustainable and circular fashion sector
Presence of several successful companies (e.g., Alma Ras, Prevent, Kotex)	Partnerships with creative sectors and educational institutions
Export potential	
Weaknesses (W)	**Threats (T)**
Dominance of the "lohn" model (contract manufacturing without brand development)	Continued population decline and labour shortage
Low wages and departure of qualified workers	Volatility of the global market
Technological obsolescence	Competition from Asia (especially China, Bangladesh)
Lack of connection with the creative and design sector	Lack of long-term government strategies
Lack of investment and government support	

Case Studies

Case studies of companies like Alma Ras, Kotex, and Prevent provide valuable insights into the development, successes, and challenges faced by key players in the textile industry in BiH. The analysis of these companies highlights different approaches to modernization, innovation, and adapting to market conditions, which could serve as a basis for future strategic directions in the sector. Alma Ras is a well-known manufacturer of textile products, particularly underwear and pyjamas. The company is recognized for the quality of its products and has a strong presence in the domestic market. Kotex specializes in the production of technical textiles and apparel. Prevent is one of the largest exporters in BiH, specializing in automotive components, but also has significant production in the textile industry. The company exports products for renowned global brands, indicating its substantial share in exports. However, specific data on their market share and share of textile industry exports in BiH is not publicly available.

Table 2. Case Study of Three Companies in the Textile Industry in BiH.

Company Name	Development	Achievements	Challenges
Alma Ras	From a small workshop to a leading manufacturer in BiH and the region; Modernization and collaboration with designers.	Stable export network, especially in the EU; Awards for quality and innovation; Commitment to sustainability and social responsibility.	Financial challenges; Bureaucracy barriers; Lack of qualified workforce.

Kotex	Traditional technical textile manufacturer; Investment in technology and capacity expansion.	Regionally recognized in technical textiles; Stable exports and collaboration with industrial partners.	Regulatory barriers; Aging workforce; Hindered innovation.
Prevent	Integrated company in the automotive and textile industry; Focus on innovation and geographical advantage.	High level of exports, modern technologies; Collaboration with global leaders; Technological superiority.	Regulatory barriers; Legislative inconsistencies; Difficulties in attracting and retaining young people.

The Fashion Scene in Bosnia and Herzegovina and Its Creative Potential

The fashion scene in BiH is developing despite numerous challenges, standing out through creativity, social engagement, and a connection to cultural heritage. Young designers are blending tradition with contemporary trends, creating an authentic expression that is gaining increasing international attention. Fashion is also being used as a means of social critique, while the industry's growth is hindered by a lack of infrastructure, legal protection, and financial resources. Nevertheless, the rise of digital platforms, fashion festivals, and international collaborations is opening up new opportunities. Key factors for further progress include investing in education, institutional support, and the promotion of domestic brands [22].

5.5. Reasons for Poor Cooperation Between the Textile Industry and the Creative Sector in BiH

Despite its long tradition, cooperation between the textile industry and the fashion scene in BiH remains underdeveloped due to numerous structural barriers. A lack of communication, differences in business culture, the dominance of the "lohn" production model, technological backwardness, and weak institutional support contribute to these sectors being isolated and lacking synergy. As a result, the opportunity to create authentic domestic products competitive in the global market is missed. A strategic initiative is needed to connect industry and design through joint projects, education, and the promotion of domestic production.

Conclusion

The textile industry of BiH has a long-standing tradition and enormous potential for development, but to fully harness its advantages, it is essential to implement reforms based not only on economic factors but also on social values. Educational reform, aligning workforce training with market needs, and ensuring a balanced territorial distribution of capacities are key steps to securing the sustainable future of this sector. At the same time, legislative regulations are needed to ensure stable development and equal treatment for the textile industry across the entire country. By connecting with the creative and design sectors, the textile industry can become a meeting point for creativity, tradition, and modern production, thereby opening doors for new generations to achieve personal development through their work and stay in their homeland. Supporting domestic fashion brands must be a strategic priority—through financing, promotion, media visibility, and by fostering a sense of collective responsibility within society for preserving and developing its identity. Through the development of a national strategy and international promotion of the quality of domestic textile and creative industries, BiH can become recognized for its authenticity, quality, and the people behind it. Ultimately, the development of the textile industry should not only be an economic goal but also a means of strengthening the community, restoring dignity to work, and creating opportunities for a better life in BiH.

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From Wearable to Artwork: A Snap-Button Skirt as a Modular Concept

Katarina Matulin, Duje Kodžoman and Jasminka Končić

University of Zagreb Faculty of Textile Technology, Department of Textile and Clothing Design, Zagreb, Croatia

E-mail: dkodzoman@ttf.unizg.hr

Abstract. This paper presents the design of a multifunctional faux leather object developed using a laser-cut technique and a snap-button closure system. The project is titled Lacuna (an empty, unfilled space or a gap) as its core concept is based on perforation and hollow shapes. The multifunctional faux leather object was designed so it could be: a) worn as a skirt, b) displayed as a tablecloth, c) exhibited as a decorative piece of art, or d) transformed into an interactive puzzle. The material selection was primarily based on durability, ensuring both visual and functional properties. This wearable object was designed with three separate layers that can all be laid flat and are connected by snap buttons. Several prototypes were constructed to improve the snap-button system and test how easily the Lacuna object can change forms, allowing multiple configurations. The research methodology consists of three steps: Design development, Material Experimentation and Prototyping of the skirt's modular functionality. This paper contributes to the ongoing discussion on expanding the role of clothing beyond traditional wearability. The results demonstrate how the snap-button mechanism enables easy reassembly and user interaction, emphasizing the potential of modular design in clothing and textiles. In addition, the paper illustrates the importance of modular concepts in contemporary fashion, offering new perspectives on how garments can function as multifunctional, dynamic objects.

1. Introduction

Multifunctional clothing is developed to address the short lifespan of garments caused by fast fashion trends, varying situational needs, or changing weather conditions [1, 2]. It is defined as clothing designed for multiple occasions and functions, catering to specific market demands [2]. The value of multifunctional clothing lies in its diversity, flexibility, and continuity [3]. Diversity allows the wearer to choose and assemble pieces, flexibility encompasses design, production, sales, use, and disposal, while continuity ensures long-term usability across seasons [3].

Multifunctional clothing is designed to be disassembled and reassembled in various ways to serve different functions [4]. Li et al. [4] identify five key characteristics in its production: (1) single-function designs, which can be disassembled for a specific purpose; (2) multi-function designs, which incorporate two or more functions through simple disassembly; (3) geometric designs, where garments are deconstructed into geometric shapes; (4) compound designs, which transform basic clothing into decorative elements using fasteners or zippers to create different garments; and (5) splicing techniques, which can be either recessive or explicit.

Multi-functionality in fashion aims to integrate digital capabilities, offering benefits such as mobility, connectivity, and physical sensing [5, 6]. This convergence of fashion and technology provides digital functionalities in close proximity to users [7]. The primary advantage of fashion as a technological platform lies in its constant presence and mobility [7]. Modular fashion focuses on the development of systems that can be easily assembled and disassembled, facilitating washability and maintenance [7]. Garments are increasingly serving as both functional elements and enablers of mobility [3]. The emphasis is on user-oriented multi-functionality, combining traditional fashion with engineering technologies [8]. Enes and Boğday Saygılı [9] examine sustainable fashion through the integration of zero-waste and modular design methodologies. Their study highlights that conventional garment production generates substantial cut-and-sew waste, with estimates ranging from 10–15% to as high as 87.6%.

Modular fashion design allows consumers to modify garments, extending their lifecycle and promoting sustainability. It involves structural components that interconnect and relate to one another, empowering consumers to personalize designs according to their preferences. Key characteristics of modular fashion design include:

- Consumer-centric design: Consumers actively participate in modifying the garment's structure.
- Extended lifecycle: Modular designs enhance garment durability.
- Adaptability: Garments can be altered to reflect the user's preferences and needs.
- Versatility: A single garment can achieve multiple looks.

Modular fashion promotes sustainability by reducing waste and encouraging responsible consumption [1, 10]. By enabling consumers to individualize their clothing, modular design fosters a stronger connection between the user and the garment [11]. This personalization can lead to increased satisfaction and prolonged garment usage. The design approach integrates consumer behaviours and purchasing habits to address sustainability concerns [11]. Extending a garment's lifecycle mitigates waste and contributes to ecological improvements [12, 13].

Building on the previously discussed concepts, the project Lacuna adopts a user-cantered, modular approach to design a multifunctional garment constructed from laser-cut faux leather and assembled using snap buttons.

2. Methods

The research methodology follows a three-step process: (1) Design Development, (2) Material Testing, and (3) Prototyping. The aim was to explore how snap-button systems and laser-cut materials could be used to build a modular, multifunctional garment.

2.1 Design Development

The design was inspired by the idea of a "*lacuna*" - a Latin word meaning a gap or empty space, which English speakers adopted in the 17th century to describe a figurative absence or missing part of something [14]. The project therefore focused on incorporating hollow shapes and perforated patterns. The goal was to design "multi-purpose" object: that could be a skirt, a decorative art piece, a table covering and an interactive puzzle.

Faux leather was chosen for its natural appearance, resilience, and laser cutting suitability. The patterns were generated using vector design software (Adobe Illustrator) and were arranged into three layers. These layers were attachable to one another with snap buttons in various shapes.

2.2 Material Testing

The faux leather underwent small-scale tests to evaluate its behaviour during laser cutting through assessments of edge quality and cut precision and material distortion. The evaluation of different perforation patterns and snap-button placements helped determine which configurations would enable effective assembly. The experimental findings led to modifications of the pattern design and button system which resulted in better structural performance.

2.3 Prototyping

Three prototypes were constructed to evaluate the assembly process and modification capabilities between uses. The hand assembly of each prototype served to evaluate main aspects:

- The effectiveness of the snap-button system.
- The proper alignment of the layers.
- The object's flexibility when transitioning between functions.

The testing process allowed us to optimize the pattern arrangement and button placement and material handling procedures, ultimately improving the modular performance and usability of the design.

3. Results

The following section demonstrates the Lacuna object transformation through its modular design and user-focused approach and adaptability features. The results are shown through photographs and digital simulations together with observational feedback.

The Lacuna object consists of three faux leather layers that are connected through snap-button closures. The layered design allows for modular changes and supports the object's function as a multi-purpose item. The perforated design pattern creates both visual appeal and material flexibility and interactive user experience (Figure 1).

Figure 1. The flat-laid design of the Lacuna object and the digital simulation of its structure and perforation patterns.

Prelimminary user interaction showed that snap-button placement directly impacts the transformation process. The object's comfort and fit as a skirt improved after strategic button alignment modifications at the back centre. The modifications led to better structural coherence of the object throughout all its modes. The design showed promising results regarding usability and flexibility and aesthetic consistency during the prototyping phase even though no formal user testing was not conducted.

The modular assembly system allows for seamless transitions between different configurations. The snap-button mechanism supports intuitive reassembly and enables the user to alternate the object’s function between a wearable skirt, a flat-surface item such as a tablecloth, a decorative wall piece, or an interactive puzzle for children. These

versatile transformations are demonstrated in a series of photographic outcomes (Figure 2).

Figure 2. Transformation of the Lacuna object and its different functions: (a) decorative art, (b) tablecloth and (c) puzzle.

The following statements describe the designer's perspective regarding functional transformations of the Lacuna object. The roles demonstrate the design goal of uniting aesthetic value with practical functionality across multiple use situations:

Transformative Art (Figure 2a)

Displayed on a wall, the layered structure functions as a decorative artwork, bringing visual interest and conceptual depth to interior spaces.

Tablecloth Functionality (Figure 2b)

When laid flat and used as a table covering, Lacuna enhances dining spaces with elegance and structure, combining visual appeal with everyday practicality.

Puzzle-Play Innovation (Figure 2c)

When used in play settings, particularly for children, the laser-cut perforations and leftover pieces serve as interactive puzzle elements. This encourages creativity and tactile learning by allowing children to reinsert cut-outs into the design.

When worn, the Lacuna skirt shows both structural stability and versatility, as seen in Figure 3. The snap-button system and layered construction enable an easily customisable fit, demonstrating the practicality of the modular design approach in a wearable form. Lacuna is a garment that fulfils the principles of multifunctional and user-centred fashion design by providing a balance between visual appeal and reconfigurability.

Figure 3. The Lacuna skirt worn as a garment, illustrating its construction and body fit (photo: Šimun Bućan).

4. Conclusion

The research explored modular fashion design capabilities and potential by developing Lacuna - a versatile garment made from laser-cut faux leather with use of snap-button assembly system. The object achieved multiple functional modes including: a wearable skirt, table covering, wall-mounted artwork and interactive puzzle. The research methodology was based on user-centred practice-based methodology that involved design development, material testing and prototyping.

The research results demonstrate the useful advantages of modular construction in the fashion industry by showing that snap-button mechanisms enable usability and personalization and reconfiguration. The design modifications which placed buttons strategically and arranged patterns improved both the structural integrity and adaptability of the object.

The modular design approach of Lacuna exemplifies how fashion can extend product life while promoting sustainable consumption and enabling user interaction and multiple uses. Observational feedback from the prototyping process revealed better usability alongside enhanced comfort and improved aesthetic coherence.

In general, this project contributes to the growing discussion about sustainable and multifunctional clothing by demonstrating a practical example of how modular design principles can be applied to contemporary fashion.

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Blue denim clothing between technological unsustainability and fashionable seduction

Sumeja Osmančević, Anesa Hadžić, Nives Murk and Irfan Hošić

University of Bihac, Faculty of Technical Engineering, Bosnia and Herzegovina

E-mail: sumejaosmancevic19@gmail.com

Abstract. This paper explores garments made from blue denim (jeans denim), focusing on their production processes, technological unsustainability, and symbolic significance in both historical and contemporary fashion. These garments have a distinctive appearance, a specific cut, and varying social implications. First introduced in the mid-19th century in the United States as durable workwear, blue denim has since evolved into a global fashion phenomenon, combining resilience with aesthetic versatility. Its popularity stems from a fusion of practicality and visual appeal. However, denim production raises serious concerns about ecological sustainability. The manufacturing process involves high resource consumption, extensive chemical treatments, and labor-related challenges within the textile industry. The production, dyeing, and washing of denim require significant amounts of water and energy, while chemical treatments and stone-washing further contribute to environmental strain. To ensure denim's future, it is crucial to reshape production methods and implement sustainable innovations—changes that are feasible if legal regulations address past shortcomings. Despite these challenges, denim's enduring appeal lies in its timeless aesthetics, cultural symbolism, and adaptability to evolving fashion trends. From workwear to a symbol of rebellion and even luxury, blue denim remains relevant and "eternally young," offering individuality through its cut, treatments, and styling.

1. Introduction

Jeans represent one of the most influential textile products of the modern era, leaving a deep mark on society, culture, and the global economy. Their widespread popularity and mass consumption are the result of a long process of technological development and cultural integration. At the core of jeans is the fabric, denim, recognized for its twill weave and distinctive indigo color, which allows it to be used across different social classes and style expressions, from workwear to high fashion. However, jeans production involves a complex technological chain that begins with cotton cultivation and ends with various finishing treatments of the fabric and garments. This process

carries significant environmental consequences, including excessive water consumption, the use of harmful chemicals, and the generation of large amounts of waste. Despite growing global awareness of their environmental impact, jeans continue to hold strong symbolic and commercial value, which further complicates efforts to implement sustainable solutions within the industry. This paper explores the complex relationship between the fashion and cultural appeal of jeans and their environmental unsustainability. Through an analysis of their historical development and contemporary challenges, it identifies key characteristics, weaknesses, and the potential for sustainable transformation of this globally ubiquitous product.

2. Historical Perspective and the Origin of the Name

In recent textile history, denim has become one of the most widely accepted and worn fabrics. It has been used and embraced by people of all ages and social classes. Although somewhat rigid in its physical characteristics, it adapts easily to fashion trends in terms of its aesthetic and symbolic value. Pants, jackets, overalls, skirts, shorts, and many other items made from this fabric have entered the clothing anthology of numerous generations as symbols of freedom and timelessness. In everyday language, the term jeans is often used interchangeably with words such as denim, trousers, jean pants. However, there are distinctions between these terms, not only in their linguistic origins but also in the materials and construction methods used in their production.

2.1 What Are Jeans, and What Is Denim?

In textile terminology, "denim" refers to a sturdy, durable twill fabric, while "jeans" refers to the garment made from denim, in other words, the finished product. Denim is a strong cotton fabric characterized by a twill weave, meaning diagonal patterns are created by dyeing the warp (vertical threads) with indigo blue, while the weft (horizontal threads), which are undyed and white, pass under at least two warp threads. This weaving and dyeing technique gives denim its distinctive textured surface and creates a fabric that appears blue on the outside and white on the inside. Originally, jeans were used as workwear, which is why only the warp threads were dyed. In that early version and for economic reasons only about 50% of the fabric was colored, reducing production costs while maintaining functionality.

The etymology of the terms themselves offers valuable insight into how denim and jeans evolved, as the definitions we use today became widely adopted largely due to the rise of jeans in the late 19th century, driven by businessman Levi Strauss. Some theories suggest that the names denim and jeans originate from the French and Italian cities of Nîmes and Genova, respectively. At the time, textile workers in Nîmes attempted to replicate a fabric originally produced in Genova. However, due to an error in the process, they ended up creating a new fabric, which soon spread throughout the world under the name "serge de Nîmes", literally "twill from Nîmes". From that phrase, the modern term “denim” was born. [1]

Scholars such as Pascale Gorguet-Ballesteros from the Musée de la Mode et du Costume in Paris believe that as early as before the 17th century, there existed a fabric made in England called "nim," which referred to twill-weave textiles regardless of whether they were made from cotton, linen, or silk. The fabric from Genova was referred to in French-speaking regions as "genes" or "jean(e)," named after the city itself. This term was later anglicized to “jeans”", which in many languages, including our own, became known as “džins.” Thanks to the company Levi Strauss & Co., a jeans culture was established originally as workwear for farmers, trappers, and cowboys in the American South. From these professions came various regional names such as “farmerke,” “traperice,” and “teksas.” [1]

2.2 History of Jeans

The history of jeans began over 400 years ago, and throughout that long journey, they transformed from clothing for workers and lower social classes into a universal cultural symbol spanning everything from everyday wear to the fashion runway. [5] Historically, the jeans we know today are not made from the same fabric as they were at the beginning. The development of jeans is complex and intertwined, framed by historical facts and legends from the past, stretching between European sailors' voyages to India and the efforts of English textile workers. This garment is marked by a nonlinear path through the story of globalization.

The fabric known as jean from Genoa in the 16th century was originally a blend of cotton and wool. By the 18th century, it was being produced exclusively from cotton and had become highly valued. Its distinguishing feature was the method of dyeing, in which all the threads were dyed blue. Meanwhile, the fabric from Nîmes, developed in the early 1600s, was an attempt to replicate the Genoese fabric. It became popular under the name “serge de Nîmes.” The word serge is defined as a twill-weave fabric made from wool, cotton, or silk, [1] and in translation, it corresponds to twill. The fabric serge de Nîmes was unique in that only the warp threads were dyed, this trait has survived in the production of modern jeans, resulting in the recognizable texture and the contrast between the darker outer side and the lighter inner side of the fabric. Denim and jean were also produced in what was then a British colony, now the territory of the United States. [2] In the following centuries, American newspapers and pamphlets showed a clear distinction between denim and jeans: denim was intended for higher-quality workwear that required durability and comfort, while jean was made for lighter work garments where comfort and longevity were less important. [1]

Everything changed with the arrival of Loeb Strauss from Bavaria to the United States, who later changed his name to Levi Strauss. In 1853, he came to San Francisco and opened a small store during the height of the Gold Rush. There, he met his business partner, Lithuanian immigrant Jacob Davis, and in 1873 they sought to implement their patent for metal rivets designed to reinforce the edges of pants seams. These rivets are

still present on jeans today, although their original function has become mostly obsolete. They were originally meant to strengthen seams during intense physical activity such as mining and farming. May of that same year is considered the birthday of Levi's (another term for jeans, specifically those produced by Levi's®), more precisely the "blue jeans," with patent number 139,121 being produced. The signature seam on jeans was introduced, especially the two arcs on the back pockets, and the Levi's design became increasingly recognizable by its yellow-orange stitching and suspenders with copper rivets around the waist features that defined the famous "501®" model. [5] The company Levi Strauss & Co. entered the fashion anthology and shaped clothing history. During the 1940s, the company adopted cowboys as their iconic figures, supported by the boom of cinema in the United States. The popularization of Western films, starring John Wayne, James Stewart, and Randolph Scott, among others, as Wild West legends fictional and historical, contributed to the spread of jeans.

American soldiers brought jeans to Europe during World War II, where their symbolism shifted from workwear to a symbol of youthful rebellion. James Dean defined the rebellious style of the time with tight, fitted Levi's; jeans became banned in schools but remained beloved by young people. Jeans became a symbol of American culture; Soviet propaganda portrayed them negatively to discourage their youth, yet jeans became one of the most sought-after garments among young people in the Eastern Bloc. From the 1980s onward, jeans became both mainstream and high fashion, a symbol of rebellion and style that endures to this day. [3]

3. Technological Processes in Jeans Production

3.1 Basic Production Processes

Denim is made using a *vat dye*, specifically indigo blue, which bonds in layers to a cotton base with a relatively loose structure. The overall production process is very similar to that of grey (undyed) fabric, up until the weaving stage. The key difference lies in the timing of the dyeing process: in denim, dyeing is done during the finishing stage, whereas with grey fabric, dyeing is decided upon only after the final product has been determined.

The first stage, opening, involves separating baled cotton fibers into smaller tufts. The fibers are then transported via an air suction system into cleaning and mixing machines, where they pass through several additional devices until they reach the carding machine. During the drawing process, six fiber slivers are combined into one uniform strand, which is further purified and aligned to prepare it for either open-end or ring spinning.

For the ring spinning method, the strand goes through an additional step called roving. In open-end spinning, the fibers are fed into a rotor and spun into yarn in a spiral motion. The yarn is then wound into large packages, ready for the next processing steps. This method results in high-quality yarn, essential for creating denim fabric. Open-end spinning machines are equipped with machines on both sides that automatically repair

broken threads. Another robot on a secondary line performs doffing, removing full bobbins and placing new ones in their place.

In ring spinning, the spinners use fibers from the drawing stage. Cotton is stretched using three steel and three rubber rollers, then twisted into yarn, which is wound onto a bobbin using a rotating voyager. The speeds of the rollers, rotor, and spindle determine the degree of twist in the yarn. The Uster Ring Expert system monitors machine stoppages and production parameters, while the automated system handles full bobbin replacement and forwards them to the next stage. Denim produced by this technique has a unique texture and appearance that cannot be replicated by the open-end spinning method. [9]

3.2 Weaving, Dyeing, and Finishing Technology

Weaving marks the final phase in denim production and plays a critical role in determining the quality of the finished garment. Denim is most commonly woven in a 3/1 twill weave, where the indigo-dyed warp threads interlace with grey (undyed) weft threads. The thread density directly affects fabric properties such as weight, tension, coverage, flexibility, tensile strength, and other physical characteristics. In production, weaving is typically performed using projectile looms, rapier looms, or airjet systems. [10]

Jeans apparel, especially jeans themselves, is made from indigo-dyed denim or from an ecru variant, which refers to undyed, naturally colored cotton fabric. After sewing, garments can be additionally dyed in various shades according to market demands. This approach allows for faster production, shorter delivery times, and a more environmentally friendly process compared to traditional fabric dyeing. There are two main types of equipment used for dyeing finished garments: paddle machines and rotary dyeing machines. Digital printing is increasingly being used as a sustainable alternative to conventional methods, as it allows the application of minimal dye with significantly lower water and energy consumption. This technology is especially suitable for smaller production batches and enables personalized, creative designs to be printed directly onto finished jeans.

The finishing process of denim is crucial in preparing the material for further garment construction, as it enhances dimensional stability, aesthetic appearance, and functional properties of the fabric. This process involves a range of mechanical and chemical treatments, including shrinkage control, sanforization, liquid ammonia treatment, and permanent press technology. In most cases, finishing and sanforization are conducted as a continuous in-line process, although depending on the equipment, these steps can also be divided into several phases. The standard denim finishing procedure includes: surface brushing, singeing (removal of surface fibers using flame), rinsing of finishing agents, addition of finishing chemicals, stretching the fabric to the

desired width, correcting weft distortions, drying, thermofixation, and finally, sanforization. [9]

4. Technological Unsustainability

Jeans production involves a series of complex technological processes, each contributing significantly to environmental strain. From the very beginning, the cultivation of cotton, one of the most water-intensive crops, poses a serious challenge to sustainability. Furthermore, dyeing stages and finishing treatments such as washing, bleaching, and mechanical distressing further worsen the environmental impact. The textile industry as a whole is responsible for approximately 10% of total global carbon dioxide emissions, with jeans ranking among its most polluting individual products. [11] According to industry standards, the production of a single pair of jeans requires:

- around 10,000 liters of water, including the amount needed for cotton cultivation, [9]
- significant amounts of toxic chemicals used during fabric dyeing and treatment,
- high energy consumption for processing, machinery, and transportation,
- and the generation of wastewater contaminated with dyes, heavy metals, and detergents. [6]

Mass production, measured in billions of units annually, further amplifies these negative environmental consequences. The rise and spread of the "fast fashion" concept has made the situation even worse. This model encourages the overproduction of cheap clothing with a short lifespan, resulting in excessive resource use and the rapid accumulation of textile waste. [12]

4.1 High Water Consumption

One of the most critical environmental challenges in jeans production concerns the enormous consumption of water. According to data from the Water Footprint Network, producing the cotton required for just a single pair of jeans can use up to 10,000 liters of water. [9] This amount is drawn from natural sources such as rivers, lakes, and underground reservoirs, whose overexploitation leads to the depletion of local water resources and the disruption of ecosystems.

In addition to cotton cultivation, later stages of production, particularly dyeing and specific washing techniques like stone wash and acid wash further contribute to excessive water use. Traditional dyeing methods involve repeatedly immersing the fabric in indigo baths, generating substantial amounts of wastewater saturated with chemicals. [13] In many cases, this water is discharged into sewage systems without prior filtration or adequate treatment.

A particularly severe issue arises in countries with underdeveloped or poorly enforced environmental regulations, such as Bangladesh, India, China, and Pakistan. In these regions, industrial waste is often dumped directly into rivers, resulting in severe

waterway pollution, mass die-offs of aquatic life, the emergence of health problems among local populations, and long-term degradation of entire ecosystems. [14]

4.2 Artificial Production of Indigo Dye

Although natural indigo was traditionally derived through the fermentation of plants from the Indigofera genus, today more than 99% of indigo used is synthetic. [15] First synthesized in the late 19th century, synthetic indigo now dominates the market due to its low cost and scalability in mass production. However, its manufacture depends on petroleum as a base raw material and involves a series of complex chemical processes.

These processes use hazardous substances such as aniline (a known toxin and potential carcinogen), formaldehyde, sulfur dioxide, and various reducing agents most notably sodium hydrosulfite. These chemicals pose not only a health risk to textile workers but are often released into the environment during dyeing, contributing to air and water pollution. [10]

Unfortunately, this practice remains widespread in many Global South countries where environmental regulations are weak or poorly enforced, and where pressure to produce cheap clothing takes precedence over concerns for environmental and human health. [14]

4.3 New Methods and Solutions for the Future

One of the most effective ways to reduce the environmental footprint of denim production is through the implementation of circular economy principles. Innovative brands like the Dutch company MUD Jeans have introduced a model that allows consumers to lease jeans and return them for recycling after use.

Figure 1: Presentation of Sustainable Denim Dyeing at Stony Creek Colors Through Natural, Plant-Based Dyes Derived from the Indigo Plant [20].

Old jeans are then processed and reused as raw material for the production of new garments, significantly reducing the need for new cotton cultivation and additional resource consumption. [16] Such concepts enable: reduced textile waste, lower water and energy consumption, extended product lifespan, and increased consumer awareness about the importance of sustainable fashion and responsible consumption.

At the same time, scientists and technological innovators around the world are actively developing biodegradable dyes and alternative textile dyeing methods. For example, the U.S.-based company Stony Creek Colors cultivates plants from the *Indigofera* genus and produces natural pigments for commercial use. Researchers are also exploring enzymatic methods for indigo reduction, which rely on specific microorganisms to convert the pigment into a soluble form eliminating the need for toxic chemicals like sodium hydrosulfite. [17] In addition to chemical innovations, advanced technological methods are gaining traction, such as: laser treatments, ozone application, and foam dyeing, exemplified by the Indigood Foam Dyeing technology used by the brand Wrangler. [18]

Figure 2: The beginning of the denim recycling process at Levi's, in collaboration with the Swedish company Renewcell, which contributes to waste reduction and enhances sustainability in denim production [21].

Factories like SAITEX in Vietnam are already setting benchmarks in this field. They utilize 98% recycled water, rely on renewable energy, and conduct manufacturing processes with minimal waste. Their approach demonstrates that sustainable denim production can become a reality with the right investments and innovations. [19]

5. The Fashion Appeal and Cultural Context of Jeans

The appeal of jeans lies in their unique ability to embody both casual comfort and stylish sophistication. Their versatility allows them to effortlessly adapt to a wide range of fashion styles from everyday wear to more refined looks.

The cultural significance of jeans is reflected in their transformation from a simple work fabric into a powerful symbol of freedom, individuality, and rebellion. Over the decades, jeans have evolved beyond their original function to become a means of expressing social attitudes and cultural identities. Today, jeans are more than just a piece of clothing, they are a reflection of the times, values, and generational change.

5.1 Jeans in Pop Culture and Media

Throughout the 20th and 21st centuries, jeans have undergone constant transformations, evolving alongside social change, cultural movements, and the development of popular aesthetics. What began as functional workwear in American society has become a global symbol of pop culture and identity.

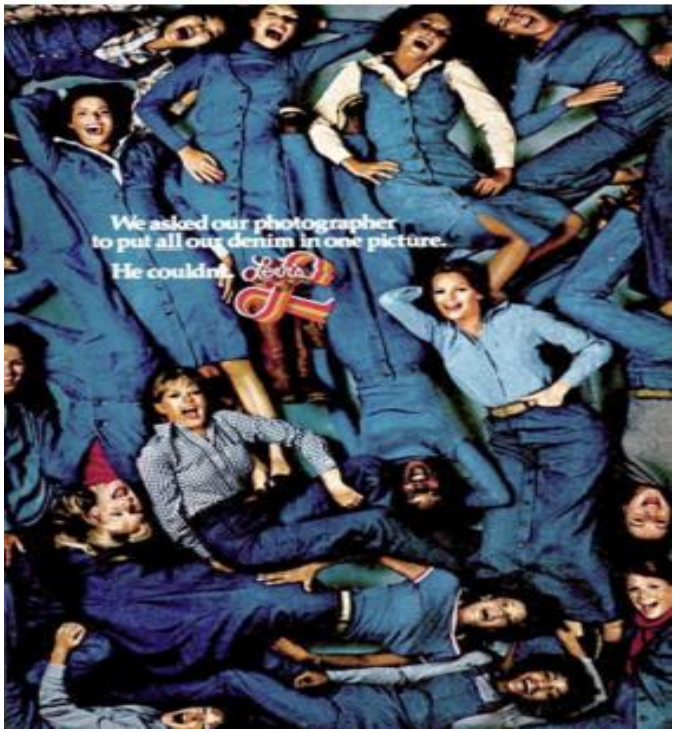

Figure 3: The demand and wealth of denim options, along with Levi's marketing campaign in Clothes Magazine from September 1976 [22].

The 1970s marked a golden era of denim diversity. Present in rock, disco, and everyday life, jeans transitioned in the 1980s into a symbol of "elitization." They entered high fashion runways and became luxury items. Brands like Calvin Klein, Guess, Sasson, and Gloria Vanderbilt introduced tight-fitting jeans with prominently displayed labels where the brand name became just as important as the design itself. During the 1990s, jeans reaffirmed their universality. They managed to retain their rebellious character through the grunge and hip-hop subcultures while simultaneously gaining commercial strength through massive ad campaigns featuring famous supermodels like Claudia Schiffer. In this era, jeans were everywhere, luxurious yet alternative, commercial yet deeply personal. [7]

In the early 2000s, especially within the Y2K aesthetic, low-rise jeans, skinny fits, and embellishments like rips and glitter took center stage. Over the past two decades, jeans have become an almost universal garment, there is hardly anyone without at least one pair of jeans or a similar piece in their wardrobe. The rise of fast fashion in the late 2010s and into the 2020s has brought new microtrends that echo every previous phase of denim culture. Today, jeans are seen as a timeless fusion of tradition and innovation, a garment that is constantly reinterpreted, yet never out of use.

5.2 Jeans as a Symbol of the Contrast Between (Dis)comfort and Attractiveness

The way we produce and wear clothing today is heavily shaped by historical patterns, and jeans are one of the clearest examples of this inertia. Originally developed as durable workwear for laborers in some of the most physically demanding jobs—such as sailors, miners, farmers, and hunters. Jeans were designed to last, while comfort was not a priority for manufacturers.

Over time, jeans have moved far beyond their functional roots to become a global cultural phenomenon. Generations have continually reappropriated them as a symbol of resistance to societal norms and a return to ideals of equality and connection with the "common person." Their appeal hasn't come from comfort, but rather from their universality and a specific kind of charm that makes them stand out in the fashion world. Today, jeans are recognized as a revolutionary garment simple, durable, and visually adaptable, that has withstood the test of time despite ever-changing fashion trends. [1]

The evolution of jeans, from modest, loose-fitting workwear to tight silhouettes and distressed fabrics that now captivate fashion runways speaks to their continual reinvention. Often overlooked as an everyday item, jeans have remained profoundly relevant. Not only have they survived decades of changing trends, but they've often led the way. [8]

Their production has also undergone major changes. From natural cotton fabrics dyed with plant-based indigo to modern synthetic dyes and the addition of elastic fibers, jeans have been technologically refined over centuries. Today's jeans

become softer and more comfortable with wear, adding to their overall appeal. Additionally, jeans pair well aesthetically with virtually any style, giving them a visual flexibility that ensures their constant presence in wardrobes worldwide.

A symbol for cowboys and feminists, hippies and supermodels, young and old alike, jeans are simultaneously cool and casual, sexy and comfortable. [8] Their stylistic versatility, combined with a rich cultural and symbolic legacy, makes them a powerful emblem of contrast. This very duality is why jeans remain a timeless garment that continues to dominate global fashion.

7. Conclusion

The production, evolution, and symbolic significance of blue jeans in contemporary society affirm their exceptional role as a textile product that transcends basic functionality. Jeans have become a global phenomenon thanks to their ability to simultaneously unite aesthetics, durability, and cultural relevance. Over their history, jeans have evolved from practical workwear designed for manual labor into a recognizable fashion symbol, all while maintaining an aura of rebellion, freedom, and social adaptability.

On the other hand, the technological aspects of denim production come with significant environmental challenges. The processes involved from cotton cultivation to dyeing and finishing techniques require enormous amounts of natural resources, particularly water, and involve toxic chemicals that pollute waterways and the broader environment. At the same time, final textile waste is often not properly recycled, contributing further to ecological degradation.

The mass production model driven by “fast fashion” exacerbates the problem. A focus on quantity over quality leads to weaker quality control, increased pollution, and a disregard for sustainability at every stage of the value chain from raw materials to disposal. For this reason, it is crucial to introduce stricter regulations that address resource consumption, enforce the use of environmentally friendly technologies, and uphold fundamental labor rights.

Despite all these challenges, blue jeans continue to hold their place in contemporary culture and markets. Their ability to adapt to cultural and fashion shifts keeps them relevant and in demand. However, the future of jeans cannot be built without consumer awareness and a shift in consumption habits. It is essential to adopt sustainable and integrated approaches that consider not only the symbolic and aesthetic dimensions of jeans but also the story behind their production and their environmental impact.

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Functional Design of Military Uniforms

Kurtović Alma and Hošić Irfan

Department of Textiles, Faculty of Technical Sciences, Bihać, Bosnia and Herzegovina

E-mail: kurtovicalma529@gmail.com

Abstract. Military uniforms primarily serve two key functions: protection and identification. The technological qualities of textiles and visual-aesthetic design, should support these functions, prioritizing comfort, practicality, and overall efficiency. The effectiveness, safety, and preparedness of soldiers in various combat scenarios, are the primary considerations for designers and manufacturers of military uniforms. Clothing technologists focus on developing and utilizing specialized materials, cuts, and technological innovations to meet the core requirements of functionality. The technological aspects of military uniform production emphasize the use of advanced materials, innovative design solutions, and modern production techniques to enhance both protection and comfort. . It is crucial that uniforms adhere to established standards for quality, compatibility, and efficiency during both the planning and manufacturing processes. This paper explores the ongoing evolution of military uniforms, driven by advancements in clothing technology, and highlights the technical and technological standards set by NATO to ensure uniform effectiveness.

1. Functional Design of Military Uniforms and Their Civil Use

The military uniform is a key element of a soldier's personal equipment, serving purposes far beyond aesthetics. It has multiple functions within modern armed forces, not limited to representing national or institutional affiliation but also including operational features that directly affect a soldier's ability to function in complex and often hostile environments. The primary functional feature of a military uniform is protection. Modern uniforms are designed to provide ballistic protection and resistance to chemical, biological, and thermal threats. With the use of advanced materials such as Kevlar and aramid fibre, functionality is defined in the design of bulletproof vests and helmets. Specialized units often use uniforms with CBRN protection (chemical, biological, radiological, and nuclear), expanding their functionality in high-risk environments.

Figure 1. View of Kevlar fabric.

Figure 2. Tactical vests made of Kevlar.

Uniforms also serve as visual identification tools. Rank, unit, country, and specialty insignias allow efficient internal organization. In military operations, such as UN or NATO peacekeeping missions, uniforms become key elements of standardization and cohesion among multinational forces. Modern uniforms are designed using principles of modularity, enabling soldiers to adapt gear to specific tasks. Features like multiple pockets, MOLLE systems (Modular Lightweight Load-carrying Equipment), and attachments for ammunition, medical supplies, and tools increase task efficiency in real time.

The design of military uniforms includes the use of camouflage patterns adapted to specific geographical and climatic conditions, whether in forested, desert, urban, or snowy environments. The comfort of a military uniform directly affects the psychophysical readiness of soldiers. Modern uniforms are made from breathable**,** antimicrobial, and waterproof materials that enable optimal thermoregulation and prolonged use without diminishing soldier performance. The functional principles that define military uniform design have also found application in the civilian context, significantly influencing the development of modern everyday clothing. Many innovations – such as thermal insulation layers, abrasion- and moisture-resistant fabrics, and modular attachments and pockets – were originally developed for soldiers in extreme conditions. However, over time, they have become part of civilian use. Uniforms are often reinforced at key areas of the body, such as the elbows and knees. It is precisely from this practicality that cargo pants, multi-pocket jackets, and garments intended for construction workers, motorcyclists, and other professions requiring protection and functionality have emerged.

Figure 3. Illustration of the MOLLE modular system (Modular Lightweight Load-carrying Equipment).

Figure 4. Example of civilian clothing inspired by military uniforms.

Military technology like thermal jackets, layered clothing, and breathable waterproof fabrics developed for extreme conditions has found use in hiking, skiing, and camping gear, proving military functionality desirable in everyday civilian contexts.

2. Innovations in Military Clothing Design

The development of military uniform clothing technology relies on interdisciplinary research across textile technology, ergonomics, and military science. Today's uniforms use advanced materials like Nomex for flame resistance and smart textiles with sensors for monitoring temperature, moisture, and the presence of toxic agents. Thanks to nanotechnology, modern fabrics are waterproof, UV-resistant, antimicrobial, and self-cleaning, reducing the need for frequent washing and improving hygiene in combat. Some fabrics even conduct electricity, enabling communication systems to be integrated directly into the uniform.

Figure 5. Representation of Nomex material in a honeycomb structure.

The technical properties of military clothing play a very important role when it comes to the protection, comfort, and functionality of soldiers in the field**.** The choice of materials, garment construction, and protective features are carefully aligned to ensure that uniforms meet a wide range of operational requirements. Modern uniforms are made from combinations of synthetic materials such as aramid and polyester due to their high resistance to fire, chemicals, and mechanical damage, often blended with natural fibre like cotton to enhance comfort. The development of the technical characteristics of uniforms continuously follows innovations in the textile and military technology industries, with the aim of optimizing protection, mobility, and operational efficiency for soldiers.

Figure 6. Representation of aramid material.

Figure 7. Representation of camouflage polyester material.

Modern military uniform production is not based solely on material selection but also involves the application of innovative technologies and design solutions**.** In addition to natural and synthetic fibre, so-called smart fabrics are increasingly being used. These fabrics have the ability to monitor soldiers' vital signs, enhance communication, or adapt to changes in the environment. The introduction of CAD systems (Computer-Aided Design) has enabled the precise customization of uniform designs to meet the specific needs of users, while **production a**utomation allows for faster manufacturing and a higher degree of quality consistency. Advanced material joining techniques, such as ultrasonic welding**,** improve the water resistance and durability of uniforms, reducing the need for traditional seams, which can represent weak points in the field.

Figure 8. Representation of a smart military uniform.

3. Standardization of Military Uniforms within NATO

NATO standards represent a set of prescribed procedures, terms, and technical requirements adopted by member countries to ensure operational compatibility and effectiveness of their armed forces. Through the STANAG (Standardization Agreement) system, NATO standards ensure that military uniforms and equipment of member states meet high demands of quality, functionality, and interoperability. The NATO Codification System (NCS) also plays a key role, allowing for the unique identification of equipment through the NATO Stock Number (NSN), which facilitates logistics and cooperation among allies. Equipment manufacturers must comply with quality norms such as AQAP standards. Uniforms adapted to NATO standards are made from materials resistant to wear, fire, chemicals, and biological threats, and are designed for maximum

comfort and functionality. Standardized camouflage patterns help reduce visibility in various environments.

4. Conclusion

The functionality of military uniforms is a key aspect of their design and production, with the efficiency, protection, and comfort of soldiers placed at the forefront. Through the use of advanced materials such as Kevlar, Nomex, aramid fibers, and smart fabrics, military uniforms have evolved into high-tech systems that meet the complex demands of modern battlefields. The introduction of NATO standards further ensures interoperability and quality within allied forces, while the use of CAD systems and automated production processes enables precise and efficient manufacturing. Moreover, many functional features of military uniforms have found applications in the civilian sector, confirming their broader social and technological significance. Ultimately, the continuous development of military uniforms reflects the integration of innovation, science, and practical needs, emphasizing the importance of an interdisciplinary approach in designing clothing that not only protects but also enhances the performance of those who wear it. From the perspective of Bosnia and Herzegovina, the textile industry sector – despite the challenges of economic transition and global competition – has realistic potential for growth in the production of functional military and protective clothing. By investing in modern technology, workforce training, and alignment with NATO standards, domestic factories can become competitive in the international market. While the domestic market is limited, it provides a foundation for specialized production, with exports representing a key opportunity for expansion. The continued development of military uniforms in Bosnia and Herzegovina, therefore, involves not only the application of innovation but also the strategic positioning of the domestic textile industry in regional and global markets. Although domestic demand is restricted, export offers a significant opportunity for growth and for strengthening Bosnia and Herzegovina's role in the global supply chain.

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Digital 3D Reconstruction of the Medieval Attire of Bosnian King Tvrtko I Kotromanić

Adnan Hajrulahović[1] and Slavenka Petrak[2]

[1]University of Bihac, Faculty of Technical Engineering, Bosnia and Herzegovina
[2]University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia

E-mail: ahajrulahovichaad@gmail.com

Abstract. The uniform is a part of the medical staff identity, which appearance has been affected and modified throughout history in accordance with social changes and status of doctors and nurses. In the context of the textile technologies, uniforms changed with the development of textile materials and clothing engineering, as well as the increasing demands of users for the design of functional and fashionably appropriate models. The main issue of medical uniforms in healthcare institutions of the Republic of Croatia is in the use of non-standardized models, which differ significantly between and within individual institutions in the context of design and the inappropriateness of clothing sizes for staff of different ages and body types. The paper presents research on the preferences and functional requirements of the uniforms for female medical staff of different age groups, sizes and body types, employed in different workplaces in the health care institutions. A survey was conducted with the purpose of establishing guidelines for the design and development of functional models in accordance with the expressed needs. Based on the research results, models of female medical uniforms were computer designed and virtual prototypes were developed, with the purpose of analyzing and verifying the models for users of different sizes and body types.

1. Introduction

One of the contemporary roles of fashion designers is the preservation of the cultural heritage of the societies in which they operate. Cultural heritage shapes our worldview, while art and culture give life meaning. Fashion, as a fusion of art and science, contributes to preserving identity and values. Bosnia and Herzegovina, rich in identities and history, offers numerous topics for research. Living in a country with kings, bans, and princesses not only inspires but also awakens pride and a sense of belonging. One of the frequently discussed topics is the attire of the first Bosnian king, Tvrtko I

Kotromanić [1]. Due to a lack of arguments and knowledge, this issue remains open for research. Unlike stable societies that have preserved information about Tvrtko's contemporaries, Bosnia and Herzegovina lost traces of its past through centuries of wars and changes. New rulers often erased the heritage of their predecessors. This paper deals with the digital 3D reconstruction of the medieval attire of King Tvrtko I Kotromanić, combining historical, archaeological, and contemporary insights with technological achievements in the textile and fashion industries. After the first paragraph

2. Historiography of the Bosnian King Tvrtko I

Tvrtko I Kotromanić (circa 1338–1391) was the most significant ruler of Medieval Bosnia. As the son of Vladislav and grandson of Stjepan II, he inherited the title of ban in 1353 after the death of his uncle, with his mother Jelena acting as co-ruler. Although formally subordinate to the Hungarian crown, Tvrtko strengthened his autonomy by exploiting political conflicts in the region. In 1357, he recognized the supreme authority of Louis I of Anjou and sent aid to Dalmatia, while simultaneously consolidating internal power and expanding his territory. After a brief exile in 1366, with the help of local nobles and the Republic of Dubrovnik, he regained power and eliminated his opponents. He expanded control over Zahumlje, Travunija, parts of Dalmatia, and southern Serbia by leveraging dynastic ties and the weakened Serbian authority. The Serbian royal crown allowed him to crown himself in Mileševa in 1377, probably using the Nemanjic crown, thereby affirming his right to the Serbian heritage. From then on, he titled himself as "King of the Serbs and Bosnia, the Coast, and the Western Lands" [2]. His kingdom encompassed Bosnia, Zahumlje, Travunija, Polimlje, parts of Zeta, Sutorina, and Konavle [3]. He skilfully balanced relations with Dubrovnik, guaranteeing trade privileges while using every conflict to strengthen his control. In 1373, with the help of Lazar Hrebeljanović and the Venetians, he defeated Nikola Altomanović, gaining territories along the Drina River. Tvrtko proclaimed himself "heir of the holy Serbian kings" and introduced the dynastic symbols of the Nemanjic family. Taking advantage of the death of Louis I (1382), he occupied much of Dalmatia — Klis, Trogir, Split, and Šibenik — and introduced a new currency known as the "Tvrtko denar". In the Battle of Bileća in 1388, he defeated the Ottomans. Although his forces participated in the Battle of Kosovo in 1389, his exact role remains unclear. Afterwards, he declared himself King of Dalmatia and Croatia. Tvrtko's death in 1391 marked both the peak and the beginning of the decline of Bosnian state power.

2.1. Archaeological Findings

Within the scope of this paper, the archaeological findings related to King Tvrtko I serve as the material basis for the attempt to reconstruct his attire. Since no part of his clothing has been preserved, concrete data for an exact reconstruction are lacking. The goal of this work is to consider all available sources that can aid in simulating his attire.

Included findings are: a golden ring, the royal seal, fragments of a burial cloak, a charter, coins, and King Tvrtko's signature. Also incorporated is the reconstruction of the tombstone of Bosnian rulers from Bobovac, which, although not belonging to Tvrtko himself but to his successors, provides important visual insight into the possible appearance of royal attire [4].

Figure 1. Royal ring.

Figure2. Brocade fragments from the Kotromanić tomb.

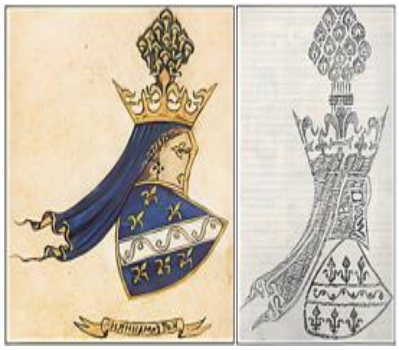

Figure 3. Reconstruction of the embroidery from King Tvrtko I's funeral cloak.

2.2. The Image of King Tvrtko I Kotromanić

The image of King Tvrtko is preserved on his large double-sided throne seal from 1377, made of red wax, with a diameter of 11 cm, featuring rich relief work. On the front side, the king is depicted seated on the throne, holding the royal sceptre and orb topped with a Latin cross—symbols of spiritual and temporal authority. On both sides of the throne are the coats of arms of the Kotromanić dynasty, surrounded by a circular inscription. On the reverse side, Tvrtko is shown as a horseman in battle armour, wearing a helmet and a fleur-de-lis crown. In his right hand, he holds a spear with a banner, and in his left, the reins and a shield. The horse is richly decorated, with a cloak displaying the coat of arms featuring lilies and a vine motif. The seal is kept at the Homeland Museum in Visoko [5].

Figure 4. Seal of Tvrtko in the museum in Visoko – front and back sides.

2.3. Contemporary Context of King Tvrtko I Kotromanić

Tvrtko I was a typical medieval ruler—he did not aim to liberate the people but to expand his own power, in accordance with the political circumstances of his time. Although claimed by three modern nations today, his legacy should not be viewed through contemporary national divisions but within the context of Medieval Bosnia [6]. This paper presents contemporary artworks and monuments representing Tvrtko I: in Tuzla (2012, by Adis Lukač), Herceg Novi (2013, by Dragan Dimitrijević), and Sarajevo (2023, by Stjepo Gavrić). The Sarajevo monument has not yet been permanently installed because the Commission for National Monuments of BiH has not given approval. Also included are visual works and sculptures by Dr Adis Fejzić[7], as well as a drawing of Tvrtko II at a wedding, which can serve as a visual reference for the reconstruction of Tvrtko I's attire.

Figure 5. Sculpture of King Tvrtko I – Kotromanić [7].

Figure 6. Monument of King Tvrtko I in Tuzla, Bosnia and Herzegovina.

Figure 7. Illustration of Bosnian King Tvrtko I in the book Kings and Queens of Bosnia [8].

3. Medieval European Costume

Throughout history, folk costume was an expression of identity, culture, and social status. Besides its aesthetic value, it had documentary significance because it reflected the environment and tradition of the wearer. Today, that function is almost lost – costumes are rarely seen, mostly in museums, films, or folklore. This paper focuses on the attire of the high class of the medieval Bosnian kingdom, especially King Tvrtko I Kotromanić. To understand his attire, one must take into account the dominant European style of that time – Gothic. Although Gothic strongly influenced the Bosnian court, there were also local style elements in the making of clothing and jewelry, which this work particularly addresses. Gothic developed into an international style by the late 14th century and dominated Europe until the appearance of the Renaissance. In some parts, like Germany and England, it lasted until the 17th century. Gothic spread

with the development of towns and trade, and the wealthy ordered artworks and luxury clothing. Detailed fabric processing, especially of dresses, became dominant in dressing, as well as an increasing importance of accessories like belts. Men's Gothic clothing was tight and shorter, while women wore long, flowing dresses. Common people's clothing remained simple – long-sleeved tunics, with an additional layer in winter, like vests. Women covered their heads with a veil or cap, and aprons only became common in the 15th century [9].

3.1. ***Medieval Bosnian Style of Dressing***

The most important textile raw material in Medieval Bosnia was high-quality wool (lana di Bosna), which was an export product. Besides wool, leather, fur, hemp, silk, and cotton were also used. Clothing was mostly made in households, while heavier tasks were done by local tailors (šavci, svitari), and in towns and courts, specialized master tailors worked [10].

Royal attire included a crown, a long dress with a belt, a cloak as a symbol of power, and decorations of gold and silver. Feudal lords accepted Western fashion influences, while lower nobility layers retained traditional clothing forms like kontuš, šuba, and svita. Men often wore svitas tightened by belts, and women used scarves to decorate and cover mirrors [11]. Garments were decorated with goldsmith products: crowns, diadems, clasps, buttons, etc. Visual and written sources (stećci, coins, illuminated manuscripts) provide information about Bosnian attire. Among them stands out the chest of St. Simeon in Zadar, depicting members of the Bosnian nobility in clothing with horizontal stripes, which could represent the "Bosnian style" (modus bosnensis*, ad modum bosnensem*)[12]. Decoration with horizontal stripes and "caknas" is considered an original Bosnian contribution, as it does not appear in contemporary French or Italian sources. Such decoration is confirmed on stećci, especially those with figures in clothing with horizontal expansions, likely expressing the local decorative style in the 14th and 15th centuries. The belt on female figures with stripes is placed according to Burgundian fashion. Stećci confirm the existence of different social layers through clothing differences. The stećak from Donja Zgošća dates from the late 14th or early 15th century and depicts hunters with belts on their hips, corresponding to Burgundian fashion. Depictions of knights with armor in a transitional phase to Gothic style indicate advanced military armament in Bosnia, also confirmed by Hrvoje's missal from 1403/1404. Reliefs from Radimlja and other places (Borje, Žitomislić) depict nobles, knights, and tournament participants in Western-style clothing, including mi-partie (two-tone) clothing and feathered caps. The reliefs also show elements of everyday life, like depictions of carts and bell-shaped dresses, all testifying to the rich and diverse culture of dressing in Medieval Bosnia.

4. Conceptual Design of King Tvrtko I Kotromanić's Attire

The reconstruction of King Tvrtko I's attire envisions a shield divided horizontally in the upper part and vertically in the lower part. The shield is black, made of leather with metal reinforcements and interwoven leather straps. The front and back of the shield in the upper part are divided into two equal sections, with additional side sections. The lower part of the shield is divided into two halves to allow unhindered horseback riding. Beneath the shield are two dresses, reaching above the knees. The lower dress is cut in a T-shape, with sleeves that are not tailored, and buttons on the sleeves that fasten them close to the arms. The dress is made of green brocade with Burgundian golden motifs. The upper dress is beige-golden, made of woven wool with golden threads, straight cut, sleeveless, also reaching above the knees. The trousers are wide, black, made of woven hemp, straight cut, with a drawstring at the waist and buttons for tightening the leg cuffs around the calves. Over the shield is worn the royal cloak made of black and brown wool with golden threads, composed of two parts and connected with a hood at the back. The cloak reaches the ankles, has gathers on the shoulders, and is tied with a string at the front of the neck. As an accessory to the attire, a kožun is used – a small cape made of black sheep leather and wool, while the boots are made of braided leather and decorated with black fur. On King Tvrtko I's head is a golden crown with six wavy lilies, shaped according to the Kotromanić coat of arms that the king used. This attire is not ceremonial, but represents the daily winter royal costume.

Figure 8. The Chest of St. Simon in Zadar.

5. Digital Development and Creation of the Model of King Tvrtko I's Attire

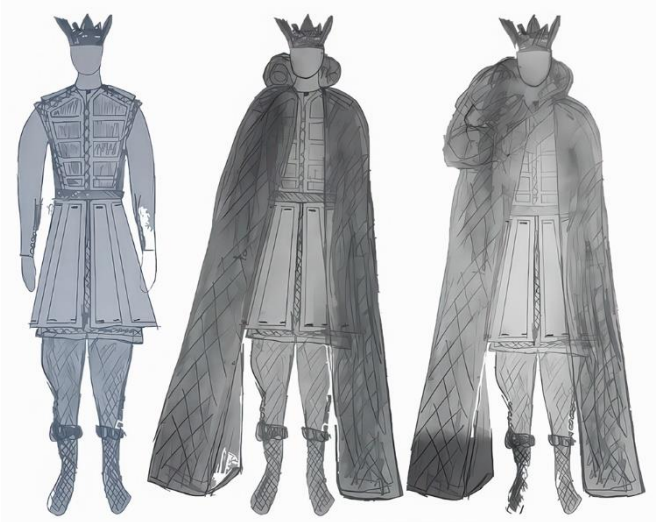

Figure 9. Concept sketch of the reconstruction of King Tvrtko I's attire.

The following sections of the paper describe the procedures of digital development, i.e., the reconstruction of the 3D model of King Tvrtko I's attire. Initially, the interface and characteristics of the CAD program CLO 3D are described, which was used to perform the experimental part of the work. Also, in one of the following sections, a digital reconstruction of King Tvrtko I Kotromanić's crown was made, as an integral part of King Tvrtko's attire.

5.1. CLO3D for Construction and Development of Digital 3D Clothing Models

CLO3D is a CAD (Computer Aided Design) software program for 3D fashion design that enables virtual, realistic visualization of clothing using the most advanced simulation technologies in the fashion and textile industry. This program is intended for creating and editing 3D garments that faithfully correspond to real clothing items, allowing ideas to be perfected before production begins. Using the CLO3D system optimizes the entire 3D design process by providing realistic textures and material visualization technologies, which enables the creation of digital shapes and designs fully aligned with the physical final product. This approach helps designers and brands unleash their creativity and achieve a flexible workflow in digital clothing model development.

From the perspective of ecology and environmental care, working in systems like CLO3D brings multiple benefits. Virtual samples enable testing and evaluation without the need for using resources and energy, which reduces waste and energy consumption.

Additionally, thanks to the possibility of remote work, designers can create and collaborate from any location with internet access [13].

5.2. Drawings and Descriptions of the Model of King Tvrtko I Kotromanić's Attire

Tvrtko I wore a crown and cloak, a course homemade woollen cape as symbols of royal dignity, and a šuba — a wide and long dress with short, wide sleeves, made of woven material in gold colour. The cloak was made as a hooded cape, known as kontuš, which is also depicted on the chest of St. Simeon. The upper part of men's clothing, constantly worn at home, was called svita. Svita was made from brocade imitation with a Burgundian style pattern. According to depictions on stećci, svita was a dress reaching to the knees or slightly below, tightened with a belt, with narrow sleeves of the lower garment that were buttoned, and very tight cuffs. The armour breastplate was heavily padded and tight, made of plate and wire parts, known as Gothic armour, covered with horizontal stripes of almost relief form, as shown in depictions on stećci, including vertical pleats falling from the belt downwards. This style of clothing and art is called Ad modum bosnensis. As inspiration and foundation for the reconstruction of the attire of the Bosnian king Tvrtko I Kotromanić, facts carved in the reliefs of stećci, the relief on the chest of Saint Simeon, and historical sources were used.

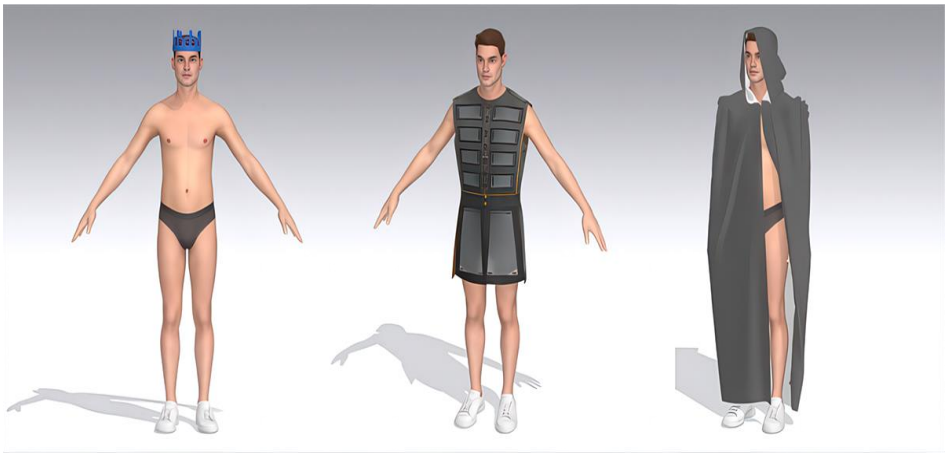

Figure 10. Development of the digital 3D model of King Tvrtko I's attire in the CLO3D interface [10].

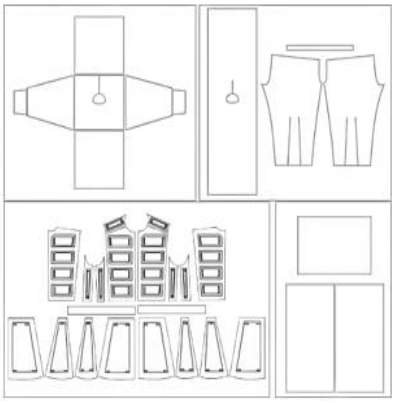

Figure 11. Technical sketch showing the pattern pieces of King Tvrtko I's attire.

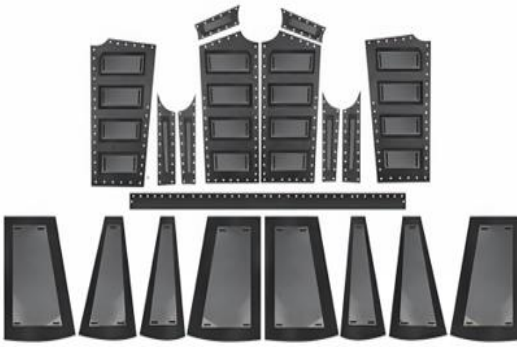

Figure 12. Digitally constructed pattern pieces of the armour with detail views.

5.3. Construction and Pattern Modelling for the Attire Model of King Tvrtko I Kotromanić

The construction for the attire model of King Tvrtko I Kotromanić is complex, considering that the attire model is intricate and consists of multiple clothing pieces. The CLO3D program offers options for assembling pattern pieces by sewing and provides certain fabric textures, but the constructed part of the attire is made from pattern pieces connected by tying and threading leather straps, with material also including metal plates. All this contributed to the complex and very demanding realization of this work. For all clothing units except the armour, the pattern pieces were constructed and dimensioned in the 2D interface, and a simulation of joining the pattern pieces into a 3D model was performed. The texture of these clothing parts was prepared as photographs by scanning real fabrics that were previously selected. Using the Materials-Graphics-Graphic 2D Pattern option, a photograph showing the texture, colour, and visual of the fabric was connected in the 2D interface and applied to all pattern pieces of the specific clothing unit. For the armour itself, each pattern piece was prepared separately in CorelDRAW 18 with all characteristics of materials, fabrics, metal plates, leather, straps, and was rendered as a photograph, then all twenty parts were imported into CLO3D and assembled into the armour that we managed to simulate. For each armour pattern piece, seam allowances were left around the piece with the vest texture so they could be joined using the sewing option in CLO3D's 2D interface.

5.4. Development and 3D Simulation of the Prototype Model of King Tvrtko I Kotromanić's Attire

By applying the CLO3D program for simulation, the patterns for the clothing items that make up the attire were constructed and modelled, and a 3D model of King Tvrtko I's attire was designed with the goal of digital reconstruction of the attire. The biggest challenge in the reconstruction was to join and sew the pattern pieces in the 3D environment, given that the program is more oriented towards simulating sewing when joining pattern pieces, rather than assembling pattern pieces using straps. The creation of the 2D construction and pattern pieces was fairly simple because the garment shapes are simple. Working in the 3D environment is inspiring, and the simulation of the attire enabled the visualization of the final result.

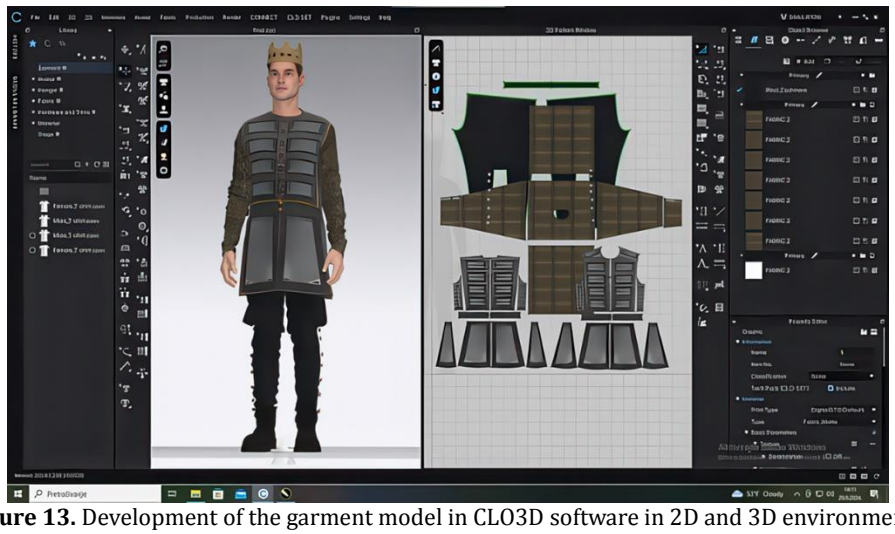

Figure 13. Development of the garment model in CLO3D software in 2D and 3D environments.

5.5. Digital Reconstruction of King Tvrtko I Kotromanić's Crown

While researching everything related to the visual aspect of King Tvrtko I's attire and preparing for the costume photoshoot conducted as part of the work, it was realized that the crown, as a symbol of royal title, would be missing in the photographs. Inspiration for the crown was found in the coat of arms of the Kotromanić dynasty to which Tvrtko belonged, which depicts a royal crown. The shape of the crown was drawn in CorelDRAW 2018. The sizing was done according to the actual head circumference, but the crown was left open so that it could be adjusted to size. Developing the idea of the crown, it was decided to realize it using a 3D printer and thus produce it. The preparation in 2D form was adapted into a 3D shape via the online platform Onshape and prepared for 3D printing. Onshape is an online CAD and PDM (Product Development Platform) platform that supports the work of modern innovators. Unlike

file-based CAD systems, which rely on unreliable references and slow check-in/check-out procedures, Onshape uses the full power of cloud architecture to overcome these challenges. Cloud-based CAD enables centralized storage of design data, eliminating data loss issues and the need for users to manage their own files. Onshape is accessible via any web browser, allowing users to securely access, manage, and share design data from anywhere in the world, on any internet-connected device. 3D printing, or additive manufacturing, is the process of creating a three-dimensional object based on a CAD model or digital 3D model [11]. This process involves various techniques in which material is deposited, fused, or solidified under computer control, adding material layer by layer (e.g., plastics, liquids, or powder grains that are fused together).

5.6. Creation of the Real Model of King Tvrtko I Kotromanić's Attire

During the creation of the real model of King Tvrtko I's reconstructed attire, great attention was paid to the consistency of the fabrics' appearance from which the garments were made, including their textures, weight, and overall visual characteristics. For the trousers, a fabric with very coarse and pronounced weaving in black colour was selected, closely resembling hand-woven hemp or linen that could have been part of the original attire. For the dress (svita), a pattern was sought that could correspond to the silk brocade pattern in the Burgundian style of that period, but such a fabric was not successfully found.

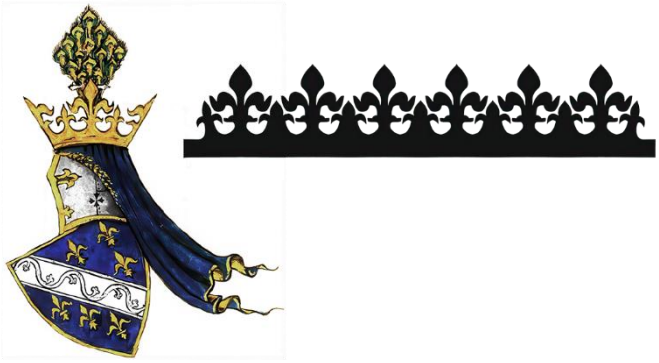

Figure 14. Kotromanić coat of arms and depiction of the drawn crown in 2D view in CorelDRAW software.

Therefore, the pattern was designed in CorelDRAW 2018 and printed onto a fabric resembling brocade using sublimation printing technology. For the over-dress or vest, a fabric was ordered that was hand-woven on a loom, as was done in the Middle Ages, which is airy and golden in colour. The cloak is made of hand-woven wool on a loom with inserted gold threads. It has weight, falls heavily and nicely. All woven materials have a width of 60 cm, which corresponds to the loom width on which they were woven. For the armour, black leather was chosen, along with 2 mm thick metal sheets and additional black artificial leather with a texture of braided leather straps. In the

supplementary design of King Tvrtko I's costume reconstruction, black sheepskin with fleece was also used, as well as gaiters to complement the footwear. Although gaiters were made, they are not the subject of this work. The appearance of the real attire was completed with the crown, as well as props such as a sword and a shield, the latter borrowed from the prop archives of the documentary film "Bosnian Knight." The svita, vest, trousers, and cloak were sewn on sewing machines, while the armour was cut, assembled, and tied by hand with leather straps without sewing.

Figure 15. Textured fabrics used for the physical model of King Tvrtko I's attire.

6. Results

The reconstructed attire of King Tvrtko I consists of trousers, a tunic-dress, an over-dress, armour, and a cloak. The crown, sheepskin (fur), and footwear were added to complete the overall look of the outfit, while the sword and shield were borrowed as props from the documentary film "Bosnian Knight." The cloak is cut from hand-woven black fabric with gold threads. It features linear forms and consists of two vertical panels with gathers on the shoulders, connected at the back by a voluminous hood. It fastens at the front with leather ties. The trousers have a straight cut, without openings, and are tied at the waist with a cord (string). The legs are straight and tightened at the calf with metal buttons, designed to fit snugly around the leg. They are made from black woven kostrijet, a coarsely woven material. The tunic-dress, known as svita, is made from brocade with a pattern matching the appearance of medieval Burgundian brocades. The pattern aligns with medieval symbolism, and it is assumed that Tvrtko I received brocades as gifts from envoys of European nobility. The brocade is green with golden details. The over-dress is made from golden lame woven on a loom. Although it is sheer, its purpose is to cushion the contact between the armour and shield, making wearing it more comfortable. The armour-shield is made of leather, connected with leather straps and decorated with braids. It is protected by metal parts that are an integral component of the armour. The armour is vertically divided into two parts: the

upper part fits snugly to the body, while the lower part is bell-shaped, skirt-like. Sheepskin fleece serves as an additional detail—a garment providing warmth. The fleece is made of black wool, which was likely valued for its rarity. The crown is described in the previous chapter. Gaiters are adapted coverings for the footwear, aimed at neutralizing the appearance of the shoes. They are made from braided leather with fur details. The shield bearing the Kotromanić coat of arms—with six lilies crossed by a silver field—and the sword were borrowed from the prop collection of the documentary film "Bosnian Knight." The photoshoot was arranged so that the costume components were combined, resulting in three variations of the outfit. The photographs were taken at the necropolis site of Dejčići on Bjelašnica in Bosnia and Herzegovina.

Figure 16. Visualization of the 3D model of King Tvrtko I's attire with armour [12].

Figure 17. Completed attire of King Tvrtko I [12].

Figure 18. Completed attire of King Tvrtko I with armor and shield featuring the Kotromanić coat of arms [12].

7. Conclusion

The digital 3D reconstruction of the medieval attire of Bosnian King Tvrtko I Kotromanić represents a research journey and process of understanding across multiple aspects — historical, archaeological, etymological, and sartorial, or fashion research. This work also touches on the sphere of identity. The research initiated here opens the topic of Bosnian King Tvrtko I, and it should be regarded as such. Various sources and methods were employed in this work. Historical records, archaeological findings, European cultural heritage—including the chest of St. Simon, one of the most important artistic works of its time—and decorations, engravings, and epitaphs from stećci tombstones were investigated. From a technological standpoint, the work relied on cutting-edge techniques such as 3D printing and different drawing programs, as well as the CLO 3D software, in which the reconstruction of King Tvrtko I's attire was designed,

constructed, and simulated. In the final stage, Tvrtko's attire was materialized and photographed at the Dejčići stećci necropolis on Bjelašnica, a site that Tvrtko most likely visited during his lifetime, as it is located near his residence. This work and the reconstruction of the attire of Bosnian King Tvrtko I Kotromanić should serve as a starting point for further research and reconstructions, as it speaks to an inexhaustible source of inspiration for work and continued studies. Tvrtko I, as the first Bosnian king, can be considered the first symbol of unity in today's Bosnian society. He is an inspiration for discussion and a source of pride for the citizens of Bosnia and Herzegovina.

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Enzymatic pre-treatment of cotton-polyester blended fabric

Stefana Begović, Lea Beličev and Anita Tarbuk

University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia

E-mail: stefana.begovic@ttf.unizg.hr

Abstract. In this work, an enzymatic pre-treatment of cotton-polyester blended fabric was carried out with the aim of activating the surface and improving the hydrophilicity of the polyester component, which can negatively affect the wearing comfort of the garment. Commercially available enzymes were used for the enzymatic pre-treatment – pectinases for the cotton component and lipases for the polyester component, with a focus on minimizing the reduction in strength. The effects obtained were evaluated according to standardized methods – change in fabric weight and strength, hydrophilicity and moisture management ability (MMT). It was found that enzymatic pre-treatment leads to better fabric properties.

1. Introduction

1.1 Cotton-Polyester Blends

Nowadays, fabrics made from blends of natural and synthetic fibers are increasingly being used. One of the best-known blends is cotton/polyester, which accounts for more than 15 % of global production and 58.45 % of the world market. The literature states that in such blends, the cotton component is responsible for the comfort of the end product. This is due to the presence of hydroxyl groups, which ensure good hydrophilicity, wettability and antistatic properties. The polyester component, on the other hand, contributes to the blend with its good mechanical properties such as strength, easy care, crease resistance, dimensional and thermal stability and quick-drying ability. By blending polyester and cotton, a material that combines the best properties of both components can be obtained, but still requires appropriate finishing to increase the comfort of the garments. To achieve this, the hydrophobic polyester component must be made hydrophilic, especially if the polyester content in the blend is higher than that of cotton and if the textile is intended for clothing or household purposes. The low moisture absorption capacity of the polyester component can significantly impair the wearing comfort of garments with a high polyester content. There are various methods for surface modification of polyester-cotton blended fabrics. Some of them are plasma treatment, alkaline processing, chitosan functionalization, enzymatic pre-treatment and many others. Recognizing that chemical treatments and

pre-treatments of cotton-polyester blends can have a significant impact on the environment, enzymatic pre-treatments are increasingly being used as an environmentally friendly solution. (1-3)

1.2 Enzymes

Enzymes can be divided into six groups depending on the type of chemical reaction they catalyze: oxidoreductases (EC1), transferases (EC2), hydrolases (EC3), lyases (EC4), isomerases (EC5), and ligases (EC6). Enzymes from the hydrolase group are mostly used in the textile industry, e.g. α-amylases in desizing, pectinases in scouring. Various enzymes can be used for the pre-treatment of PET materials: lipase, esterase, cutinase, protease, papain, laccase, and glycosidase, but the most commonly used due to their superior performance are lipases and cutinases. The use of enzymes is considered more favorable compared to conventional methods and treatments for four main reasons: shorter reaction time, lower reaction temperatures that save energy, lower water contamination due to nearly neutral pH, and minimal fiber damage thanks to their specific action on the surface-level of the target substrates. (4-6)

Among lipases, aminolipase stands out for its ability to hydrolyze the polyester surface even in mildly acidic media. In general, they have the ability to hydrolyze the waxes of cotton fiber and modify the hydrophilicity of polyester fibers, when used under optimal conditions. The improvement of hydrophilicity, significantly facilitates further textile finishing processes while maintaining good mechanical properties. (7-9)

Pectinases are considered a heterogeneous group of related enzymes that hydrolyze pectic substances of plant origin in scouring and retting processes. They are obtained through extraction from various microorganisms such as bacteria and microfungi. These enzymes are most stable within a pH range of 5 to 6, but genetically modified microorganisms can be used to produce alkaline pectinases that are active in a pH range between 8 and 9. (10)

2. Experimental

2.1 Materials and methods

A 50/50 cotton-polyester blend fabric was used, which was supplied by Čateks d.o.o. (Čakovec, Croatia). The fabric was woven in basket weave (Panama) 2/2, having mass per unit area 170 g/m^2. The fabric was enzymatically pretreated with pectinase (Biosol PRO), lipase (Texsazym) and their combination. The pretreatment was carried out with 2 % owf (over weight of fabric) of each enzyme by exhaustion method at 60°C for 1 h in the drum of Polycolor Turbomat P4502 (Mathis) at LR 1:10.

The changes in mechanical properties were analyzed by determining the breaking force and elongation according to ISO 13934-1:2013 *Textiles — Tensile properties of fabrics — Part 1: Determination of maximum force and elongation at maximum force using the strip method* with the TensoLab dynamometer (MESDAN-LAB), clamping

distance 100 mm, pretention 2 N, in warp direction. The changes in breaking force (ΔF) was calculated in relation to the start fabric.

The mass per unit area was determined by weighing on a digital scale ALJ 220-5DNM (KERN) with an accuracy of 0.0001 g according to ISO 3801:1977 *Textiles — Woven fabrics — Determination of mass per unit length and mass per unit area*. The change in mass per unit area (Δm) was calculated in relation to the start fabric.

The ability to manage liquid moisture according to AATCC TM 195-2017 *Liquid Moisture Management Properties of Textile Fabrics* with the Moisture Management Tester MMT M290 (SDL Atlas).

The pretreatments and labels are listed in Table 1.

Table 1. Pre-treatments and Labels

Label	Pre-treatment
N	Cotton-polyester blend – start fabric
T	Cotton-polyester blend – fabric pre-treated with commercial lipase Texazym
BP	Cotton-polyester blend – fabric pre-treated with commercial pectinase Beisol PRO
BPT	Cotton-polyester blend – fabric pre-treated with commercial lipase and pectinase

3. Results and discussion

In this paper, the influence of enzymatic pre-treatment of cotton-polyester blended fabric was researched. For this purpose, fabrics in basket weave were pre-treated with 2% owf pectinase (Biosol PRO), lipase (Texazym) and their combination by exhaustion method. The change in fabric properties of the enzymatically pretreated fabrics were determined.

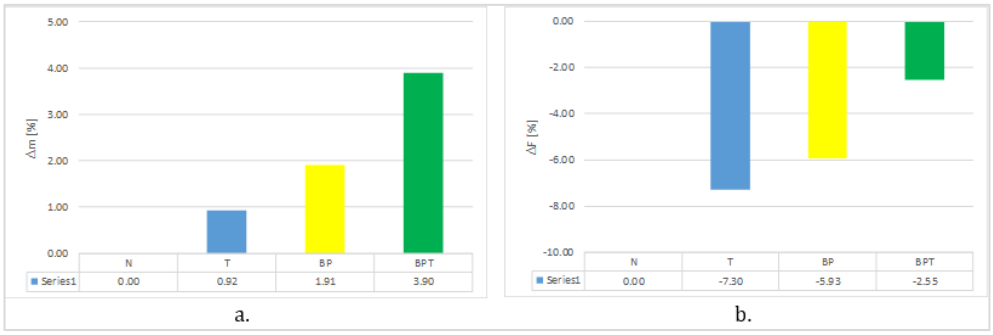
The results of mechanical properties, i.e. mass per unit area, breaking force and elongation of the cotton-polyester blended fabric before and after enzymatic pre-treatment are collected in Table 2. The change in mass per unit area and breaking force were calculated, and the results are shown in Figure 1.

Table 2. Mass per unit area (m), breaking force (F) and elongation (ε) of cotton-polyester blended fabric before and after enzymatic pre-treatment

Sample	m [g/m^2]	F [N]	CV(F) [%]	Ɛ [%]	CV(Ɛ) [%]
N	169.81	1096.0	2.530	11.55	1.839

T	171.38	1016.5	1.229	12.60	3.367
BP	173.06	1031.0	2.018	14.25	1.489
BPT	176.43	1068.3	0.390	14.33	1.843

The stated mass per unit area of 170 g/m^2 was confirmed. It can be seen that mass per unit area increased during enzymatic pretreatment, although the fabrics were surface modified. The reason for this is that the cellulose component swells strongly during wet processing, and the fabric shrinks after drying. Since only the cellulose component in the blend swells, the difference between enzymes used – pectinase and cellulose results in different swelling. Esterase aimed for polyester (Sample T) does not change cellulose, so the increase is not so high, less than 1%. However, when pectinase is used, the swelling is higher, and the increase in mass is 2%. When both enzymes were used, the increase was 4%, indicating that the polyester component also had some influence.



a. b.

Figure 1. The change in mechanical properties of cotton-polyester blended fabric before and after enzymatic pre-treatment: a. Mass per unit area (Δm), b. Breaking force (ΔF).

Polyester fibers are known for their excellent mechanical properties. From the results of the breaking force, it can be seen that the breaking force is the highest for start fabric. By applying esterase, surface hydrolysis takes place and the cleavage of the polymer chains leads to an increase in the number of terminal hydroxyl (-OH) and carboxyl (-COOH) groups, but this shortening of the chains results in lower strength. Therefore, the breaking force is lowest for Sample T with a loss of -7.3 %. After enzymatic pre-treatment, it can be observed that all fabrics show better elongation, while the loss of breaking force is only 3-7%. The best results were obtained with enzyme combination because it was 1% of pectinase + 1 % esterase, so that the hydrolysis of the polyester was controlled, and the swelling and shrinkage of cotton component contributed keeping the fabric strength.

The results related to liquid moisture management capability are presented in Table 3, with the mean values and coefficients of variation (CV) for each property analyzed for both sides of the each fabric, top (T) and bottom (B). The measurements included the measurement of next properties: wetting time (WT), absorption rate (AR), maximum wetted radius (MWR), spreading speed (SS), one-way transport capability (R), and overall moisture management capability (OMMC).

The wetting time (WT) measured in MMT is defined as the time required for the top and bottom of the sample to show the first signs of wetting (14). The data in Table 3 show that the cotton/polyester blend starting fabric has a wetting time of 5.4 s, a high absorption rate and a large wetting area, while the spreading speed is < 6 mm/s. The enzyme pre-treatment shortens the wetting time to <2.5 s. The polyester component hydrolyzed with esterase increases the spreading speed to 7 mm/s and the maximum wetting radius is larger (>25 mm), which is indicative of this. In the case of the enzyme pre-treated fabrics, the shorter wetting time is due to surface changes on the fibers, which also enable better absorption in the polyester component, as the water binds to the new chemical groups formed during pre-treatment. The absorption rate refers to the average dynamics of liquid absorption on both sides of the fabric during the first test phase. The results obtained for all tested samples confirm a pronounced hydrophilicity. Moisture is absorbed almost immediately, while the maximum wetting radius reaches more than 25 mm. As a result, the spreading speed, which measures how moisture spreads from the center of the sample to the edges, is faster.

Table 3. Moisture management properties of cotton-polyester blended fabric before and after enzymatic pre-treatment

Sample		N		T		BP		BPT	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV
WT (s)	T	5.351	1.0544	2.390	0.0679	2.437	0.0628	2.461	0.0785
	B	5.421	1.0544	2.508	0.0639	2.484	0.0377	2.578	0.0365
AR (%/s)	T	72.442	0.1596	63.984	0.0179	66.242	0.0152	63.508	0.0273
	B	80.585	0.3051	62.022	0.0147	63.886	0.0072	62.501	0.0030
MWR (mm)	T	23.75	0.1053	25	0	25	0	25	0
	B	25	0.1633	27.5	0.1050	25	0	25	0
SS (mm/s)	T	5.494	0.4721	7.073	0.0220	6.612	0.0344	6.774	0.0314
	B	6.155	0.2636	7.266	0.0568	6.557	0.0140	6.726	0.0263

R (%)	125.806	0.1747	77.177	0.2176	73.788	0.1696	86.039	0.1239
OMMC	0.624	0.0720	0.536	0.0390	0.537	0.0236	0.547	0.0222
Type	Moisture Management Fabric		Fast Absorbing and Quick Drying Fabric		Moisture Management Fabric		Fast Absorbing and Quick Drying Fabric	

Accumulative one-way transport capability (R) represents the difference between the area of the liquid moisture content curves of the top and bottom surfaces of a specimen with respect to time. For start cotton-polyester fabric R is 125% indicating that water content on top surface is much higher than on bottom suggesting high absorbency. Enzymatic pre-treatment significantly lower R to 70-80% indicating that water content top surface is lower than the one on fabric bottom surface. This suggests that the liquid introduced to the bottom surface is slowly transferred to the top surface.

Overall moisture management capability (OMMC) is calculated as a combination of three key factors: the absorption rate on the bottom side, one-way transport capability, and the highest achieved spreading speed on the bottom side of the fabric. OMMC serves as an indicator of the fabric's overall efficiency in managing moisture. For the start cotton-polyester fabric, this index shows excellent results, confirming its suitability for applications that require effective moisture management, which does not change in pectinase pretreatment. However, esterase pretreatment of polyester component results in fast wetting, absorption and spreading, large spreading area, but fair one-way transport, so the blends treated with this enzyme (sample T and BPT) are characterized as Fast Absorbing and Quick Drying Fabric.

3. Conclusion

In this study, the effects of enzymatic pretreatment on the properties of a cotton-polyester blended fabric were investigated. For this purpose, the fabric in basket weave was pretreated with two types of enzymes (lipase and pectinase) and a combination of both enzymes. The changes in mechanical properties and liquid moisture management capacity were analyzed.

From the measurement results it can be concluded that the enzymatic pre-treatment causes changes on the surface of the material. Although lipase and pectinase act on different components of the fabric, they both contribute to increased hydrophilicity while maintaining the strength of the material. Pretreatment with pectinase improves the properties of blended fabrics that have excellent transport and the fabric type is "Moisture Management Fabric". However, the esterase pretreatment changes the accumulative one-way transport capability so that the liquid introduced

into the bottom side is slowly transferred to the top side, so that the fabrics are “Fast Absorbing and Quick Drying Fabric”.

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Artificial ageing of polyester fabric: a comparative analysis of sunlight, rain and window glass exposure

Tihana Dekanić, Ana Šaravanja and Tanja Pušić

University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia

E-mail: ana.saravanja@ttf.unizg.hr

Abstract. The climatic conditions of an ecosystem directly affect the properties of textile products, with the dynamics of changes depending on the material type and exposure conditions. The intensity of these changes is influenced by factors such as temperature, solar radiation, transition between day and night, and other atmospheric conditions. This study examines the effects of artificial ageing caused by direct sunlight, alternating rain/sun, and exposure behind window glass on the properties of standard polyester fabric. Artificial ageing was conducted under controlled conditions in accordance with ISO 105-B04:1994 and ISO 105-B02:2013 standards for 85 hours. The polyester fabrics were analyzed before and after artificial ageing by evaluating their spectral properties, electrokinetic characteristics, and functional groups using Fourier-transform infrared (FTIR) spectroscopy. The results indicate that the spectral properties of polyester fabrics undergo the most pronounced changes after 85 hours of direct sunlight exposure. Additionally, the electrokinetic properties of the aged fabrics show notable changes in the alkaline range when compared to the unaged polyester fabrics, with the greatest alterations observed after alternating rain/sun and behind window glass exposure. FTIR analysis revealed minor changes at a wavelength of 2905 cm^{-1}, indicating oxidation at the C-H bond.

1. Introduction

Polyester fibres represent one of the most commonly used synthetic materials for textile applications due to their special physical and chemical properties. The hydrophobic nature of polyester fibres (PES) leads to minimal water absorption and moisture retention, which contributes to fast drying behaviour and simplified care requirements [1]. These materials have outstanding mechanical properties, including excellent dimensional stability, reduced creasing and improved wear resistance, which together ensure a longer service life in various applications. Despite these favourable properties, PES textiles have certain limitations that affect their practical application: reduced wearing comfort, increased susceptibility to soiling and pronounced static build-up [2]. Understanding these properties is crucial for the optimisation of PES textiles under

real-life conditions. The degradation of textile materials, including PES fabrics, occurs through complex interactions between chemical, physical and combined environmental factors. These processes occur under both wet and dry atmospheric conditions and are influenced by numerous variables such as acid precipitation, solar radiation, temperature fluctuations, humidity variations and other atmospheric parameters.

Natural ageing processes of textiles occur over long periods of time, making direct observation and quantification difficult for practical research purposes. Artificial ageing methods provide an effective solution by accelerating the degradation processes while maintaining correlation with natural weathering conditions [3]. These accelerated testing protocols can reproduce damage patterns, structural deformations and performance degradations that would occur in nature over days, weeks, months or years, in a compressed time frame of a few days. The synergistic approach used in artificial ageing utilises realistic environmental parameters such as temperature, humidity and solar radiation and only accelerates the temporal cycles. The main objectives of artificial accelerated ageing include identifying the main degradation mechanisms [4], quantifying the changes in mechanical properties [5], evaluating the durability of materials [6] and generating performance data for specific applications. Atmospheric factors have direct and diverse effects on material properties and contribute primarily to material degradation processes [7]. Among these variables, temperature is one of the most important parameters influencing the degradation rate and mechanisms.

In this study, the artificial ageing behaviour of PES fabrics under controlled environmental conditions is investigated. The research examines the effects of direct sunlight exposure, alternating rain/sun cycles and exposure through window glass on the degradation properties of PES fabrics. Through accelerated ageing protocols, this work aims to link artificial ageing parameters with natural weathering processes to predict the long-term performance and durability of the material.

2. Materials and methods

The effects of artificial ageing processes was monitored on a standard PES fabric with a warp/weft density of 27.7/20.0 threads/cm, a thickness of 0.35 mm, a fabric weight of 156.0 g/m2, white colour and plain weave, provided by the Centre for Testmaterials BV Employees, CFT, Netherlands.

The PES fabric was subjected to 85 hours of artificial accelerated ageing simulation using a Xenotest 440 (SDL Atlas) device in accordance with the EN ISO 105-B02+A1:2013 and EN ISO 105-B04:1994 standards. The PES fabric was exposed to three different conditions simulating artificial ageing: direct irradiation without spraying, irradiation behind window glass and simultaneous exposure to rain and sun. The exposure conditions were determined on the basis of typical conditions in the

temperate zones of Europe. The labels of the samples are defined and explained in Table 1.

Table 1 The labels and description of polyester fabrics before and after the artificial ageing.

Samples	Description of PES fabrics
PES_N	Untreated fabric
PES_85H	Fabric aged 85 hours
PES_85H_R/S	Fabric aged 85 hours with alternating rain/sun cycles
PES_85H_320	Fabric aged 85 hours with change of the filter glass (Xenochrome 320; behind the window glass)

The spectral properties were measured on a Spectraflash spectrophotometer SF 300, DataColor on the basis of 5 individual measurements according to EN ISO 105-J02:2003. The physicochemical properties of the standard and aged PES fragments were analysed by Fourier transform infrared spectroscopy using attenuated total reflectance (FTIR, Fourier Transform Infrared, Spectroscopy, PerkinElmer) in the wavelength range of 4000-650 cm^{-1}. The zeta potential was analysed using the streaming potential method in the SurPASS electrokinetic analyser, which is equipped with a titration unit and an adjustable gap cell (AGC) and controlled by Attract Software 2.0 from Anton Paar GmbH, Graz, Austria (Figure 1).

a b c

Figure 1. a) SF 300, DataColor, b) FTIR, Fourier Transform Infrared, Spectroscopy, PerkinElmer, c) SurPASS electrokinetic analyser, Anton Paar GmbH.

3. Results and disccusion

The spectral characteristics are shown in Table 2.

Table 1. The spectral characteristics of samples

Samples	W_{CIE}	TV	YI	Deviation of the hue colour from the neutral white standard	
PES_N	68.8	-0.9	4.65		
PES_85H	66.2	-1.0	5.15	R1	Trace redder than the white standard
PES_85H_R/S	66.9	-0.9	5.01		
PES_85H_320	67.1	-1.0	4.99		

The measurements of the spectral properties show that standard PES fabrics undergo certain changes after artificial ageing with various Xenochrome filters. The degree of whiteness (WCIE) of untreated standard PES is 68.8, while the yellowness index (YI) is 4.65. The spectral properties change when exposed to light. In direct sunlight, the degree of whiteness decreases to 66.2, while the yellowness index increases to 5.15. With alternating rain and sun, the whiteness decreases to 66.9 and the yellowness index increases to 5.01. The reason for the increase in whiteness and the decrease in yellowness index is due to the rain cycle in this type of sun exposure. The rain acts as a natural cleaning mechanism by physically removing the surface layer damaged by UV radiation and exposing the underlying polyester, which retains better optical properties than the photodegraded surface material.

When using the filter system that mimics the irradiation behind window glass, the smallest changes occur compared to other filters and conditions. The whiteness decreases to 67.1 and the yellowness index increases to 4.99. These observed changes are consistent with the expected behaviour, as UV radiation affects the PES component and leads to a lower whiteness and more yellowing [8]. The filter behind window glass shows a slightly slower progression of degradation and a lower impact of UV radiation on the fabric.

Figure 2 presents the zeta potential of PES fabrics before and after artificial ageing.

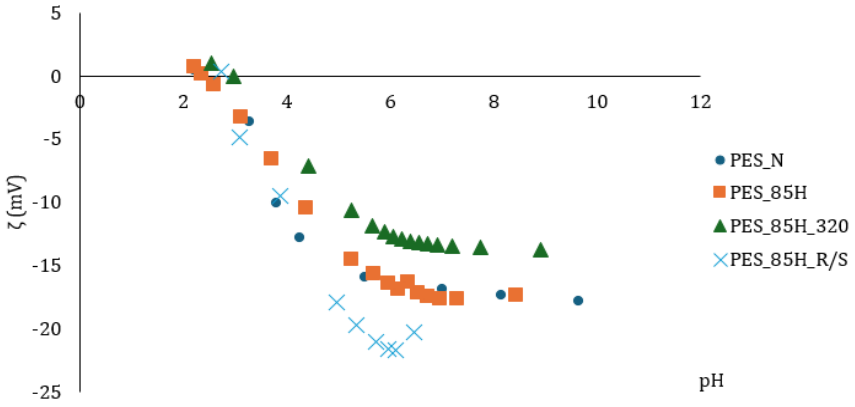

Figure 2. The zeta potential of PES fabrics before and after artificial ageing as a function of pH 1 mmol/L KCl.

The titration curve obtained for the PES polyester fabric shows zeta potential values that are less negative than those typically reported in the literature for polyester fabrics. Under alkaline conditions, the zeta potential values for this sample were around -17.88 mV [9]. Previous studies have shown that this original standard PES fabric contains a small amount of residual finishing agents that mask the surface and prevent complete dissociation of the active functional groups [10]. The zeta potential measurements for the artificially aged polyester fabric (PES_85H) showed a slight decrease in the negative zeta potential compared to the standard (-17.41 mV), which was measured in the alkaline pH range.

If filter system is replaced (the Xenochrome 300 with the Xenochrome 320), the negative zeta potential decreases compared to the standard and to the fabric aged by direct sunlight and is -13.73 mV. When changing from rain/sun, the negative value of the zeta potential increases to -20.30 and further to -21.69 mV through titration.

In the general process of artificial ageing, it was observed that the number of –COOH groups increases, therefore the zeta potential value should be more negative compared to the standard polyester fabric, except for the change behind the window sill, where a significant decrease in the zeta potential value is observed. A shift in the isoelectric point of the aged samples to around pH 2.7 compared to the standard value of 2.3 is observed, which also indicates the effects of artificial ageing on the properties of the fabric.

Figure 3 presents the FTIR spectra of PES fabrics before and after artificial ageing.

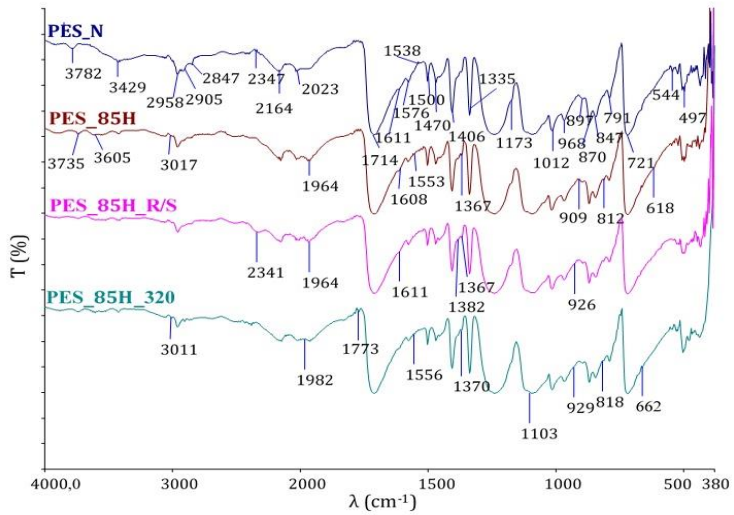

Figure 3. FTIR spectra of the samples.

The FTIR bands show characteristic peaks for polyester: C=O at 1714 cm^{-1}; 1406 cm^{-1}; 870 cm^{-1}. The peak at 1500 cm^{-1} is characteristic of the aromatic ring. Changes are observed in the region around 2905 cm^{-1} where oxidation occurs at the C–H bond [11-13].

4. Conclusion

The analyses carried out show that artificial ageing under various Xenochrome filters substantially affects the spectral and surface properties of standard polyester fabrics. The observed decrease in whiteness and the simultaneous increase in the yellowing index, which is particularly pronounced under direct irradiation, provide quantitative evidence of the UV influence on polyester fabrics. The zeta potential measurements indicate an ageing-related change in the surface properties of the fabric, with a predominant trend towards increasingly negative values reflecting the increased formation of carboxyl groups (–COOH). However, the minimal changes were observed when ageing occurred behind window glass, indicating a protective effect of the window glass against UV exposure. The observed shift of the isoelectric point is an additional confirmation of the chemical changes caused by artificial ageing processes. The FTIR analysis confirms these photodegradation effects by identifying oxidative structural changes within the polymer matrix. These experimental results demonstrate the marked sensitivity of polyester materials to environmentally induced photodegradation and emphasise the critical need to implement effective UV protection strategies to maintain the performance and structural integrity of textiles over a long lifetime.

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Environmentally friendly processing of polyester/cotton fabrics to achieve heat resistance

Sandra Flinčec Grgac, Ana Palčić, Marija Kopljar, Lea Beličev, Klarisa Čop and Marija Vaskova

University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia

E-mail: ana.palcic@ttf.unizg.hr

Abstract. One of the most important properties to be achieved with cellulose materials and their blends are heat and flame resistance. The finishing process for this purpose requires the use of flame retardants, usually based on organophosphorus compounds, to which a nitrogen-containing cross-linking agent is added and stimulates the reaction of the agent with the cellulose and forms a cross-linked structure that ensures stable, non-flammable properties. However, burning materials treated with organophosphorus compounds with halides can produce harmful and toxic compounds. To reduce the amount of formaldehyde, polycarboxylic acids are used as crosslinkers instead of melamine-formaldehyde compounds and halogen-free organophosphorus compounds are used to prevent the formation of toxic substances. In this work, a polyester/cotton blend fabric in twill weave was treated with a bath containing an organophosphorus flame retardant and a low-formaldehyde melamine resin (Ap I). The effect of the treatment with Ap I was compared with a treatment with citric acid (CA), a halogen-free organophosphorus flame retardant with added chitosan (Ap II). The samples were impregnated on a padder (Benz, Switzerland) with a wet pick-up of 100% and then irradiated with microwave, dried at 100 °C and thermocondensed at 150 °C in a stretch dryer (Benz). After treatment, half of the samples were subjected to a wash cycle in accordance with the EN ISO 6330:2021 standard to determine the durability of the treatment of the material. The thermal stability of untreated and treated samples before and after the care process was investigated by thermogravimetric (TG) analysis, while the mechanical properties were tested using a MesdanLab Strength Tester laboratory dynamometer in accordance with the EN ISO 13934-1:1999 standard. Compared to the untreated samples, the treated and washed samples show a decrease in breaking strength and elongation in the warp direction, while the strengths in the weft direction remain similar and the elongation at break increases slightly. The TG analysis revealed a higher heat resistance of the sample treated with Ap I, while Ap II shows a slightly lower heat resistance, but also a lower decrease in heat resistance after the maintenance procedure. From the results, we conclude that the use of more environmentally friendly agents to achieve the heat resistance of polyester/cotton fabrics ensures the desired functionality with less negative impact on the environment.

1. Introduction

Textile finishing refers to a variety of processes aimed at achieving the desired properties of textile materials. This often involves the use of substances that can be harmful to human health and the environment. Cellulose-based materials are used in many areas of human activity and, due to their natural properties, are often subjected to various finishing processes in order to meet the requirements of end users. One particularly important property sought in finishing is to reduce the flammability of textile materials [1]. In recent years, research has focussed on the development of treatments for cotton to improve its combustion properties, ensure compliance with safety regulations and expand its application in the textile industry for the production of heat-resistant materials. Flame retardant treatments are generally categorised into four groups: those involving halogens, inorganic compounds, organophosphorus formulations and nitrogen-based formulations. Phosphorus and nitrogen-containing flame retardants react with cellulose to form cross-linked structures that permanently reduce the flammability of fibres [2].

The combustion of materials treated with organophosphorus compounds and halides leads to the release of harmful and toxic substances [3-4]. Due to the increasing awareness of the negative effects on ecosystems and human health, alternative phosphorus-containing compounds such as tetrakis(hydroxymethyl)phosphonium chloride (THPC) and N-methylol-dimethylphosphonopropionamide (MDPA) have been developed. These compounds have low toxicity but often require the use of cross-linking agents that release formaldehyde, a compound that is considered carcinogenic and mutagenic. Therefore, research has shifted towards formaldehyde-free finishing alternatives [2].

Yang et al [5-6] investigated 1,3-dimethylol-4,5-dihydroxyethyleneurea (DMDHEU) as a binder in flame retardant finishes, but it was found to release formaldehyde. To reduce the formaldehyde content, polycarboxylic acids were investigated as substitutes for melamine-formaldehyde compounds. Yang and colleagues [7-8] investigated the use of 1,2,3,4-butanetetracarboxylic acid (BTCA), while Vivod et al [9] investigated the use of unsaturated maleic acid and a phosphorus-containing inorganic compound on cotton fibres. Blanchard [10] investigated the suitability of certain phosphorus-containing polycarboxylic acids to reduce the flammability of cotton and polyester/cotton blends. Katović et al [11] investigated the use of citric acid (CA) and BTCA as environmentally friendly crosslinking agents for the treatment of cotton fabrics with the aim of flame retardancy using an organophosphorus compound (N-hydroxymethyl-3-dimethylphosphonopropi-onamide). The results obtained were compared with those obtained with a conventional melamine-formaldehyde-based compound that increases flame resistance through nitrogen–phosphorus synergy. In their previous research, Katović et al [12] identified sodium hypophosphite monohydrate (SHP) as a highly effective catalyst when used with polycarboxylic acids (PCA). SHP catalyses the formation of bonds between the polycarboxylic acid and cellulose, with cellulose phosphorylation occurring as a parallel reaction [2]. Further studies by Flinčec Grgac et al [13-16] confirmed that citric

acid (CA) acts as a crosslinker with organophosphorus compounds in the flame retardant treatment of cotton and polyester/cotton fibres.

Current approaches in the textile industry are increasingly focussing on technologies that support sustainable development. One promising technology in this context is the use of microwave energy at various stages of textile finishing. Although microwaves are most commonly associated with drying processes, their effectiveness has also been confirmed in thermocondensation and various other textile treatment processes [17]. Due to its low energy potential, microwave energy does not lead to direct changes in material structure, but significantly increases the speed of chemical reactions [18]. Another advantage of microwave energy is the considerable reduction in the content of free formaldehyde due to the interaction with the polar molecules of formaldehyde. During treatment, the microwave energy causes heat to spread from the interior of the material towards its surface, a path that formaldehyde also tends to follow, which ultimately leads to a reduction in the formaldehyde content in the textile material [19-20].

2. Experimental part

2.1 Methodology

In this study, a polyester/cotton blended fabric (surface mass: 173.5 g/m^2; yarn count of warp 20 cm^{-1} and weft 25 cm^{-1}; twill weave K3/1) was treated with the Ap I bath containing an organophosphorus compound (Apyrol CEP ECO, CHT Group, Germany) as a flame retardant and a melamine resin (Tubicoat FIX HT, CHT Group, Germany) with a low formaldehyde content.

The efficacy of the samples treated in Ap I was compared with the samples treated in Ap II bath in wich using citric acid (CA) (Sigma–Aldrich-Merck KGaA, Germany) as cross-linking agent, halogen-free flame retardant (Exolit OP 550, Clariant, Switzerland) and chitosan (Tricomed SA, Poland). The measured pH value of the prepared bath Ap I was 2.32, that of Ap II 2.92 at a temperature of 25 °C. The samples were impregnated on a padder (Benz, Switzerland) with a wet pick-up of 100% and then irradiated with microwave energy (SHARP, YC-GG252A, Japan) at 80% power for 15 minutes, followed by drying at 100 °C for 2 minutes and thermocondensation at 150 °C for 6 mintes in a stenter (Benz, Switzerland). After treatment, half of the samples were subjected to a washing according to the EN ISO 6330:2021 standard [21] to assess the durability of the treatments on the material. Washing was carried out in a domestic washing machine (MIELE, Germany) using 5 g of a phosphate- and optical brightener-free detergent (WFK 88031) at 40 °C for 30 minutes. The thermal stability of the untreated and treated samples was analysed both before and after washing by thermogravimetric analysis (TGA, PerkinElmer, Pyris, United States) at a synthetic air flow rate of 60 ml/min. Thermogravimetric (TG) data were recorded in a temperature range of 50 °C to 850 °C at a heating rate of 30 °C/min.

The mechanical properties of the samples were also evaluated, including yarn density, tensile strength and elongation. The number of warp and weft yarns (density)

was determined before and after the washing cycle. Breaking strength and elongation in warp and weft direction were tested with a MesdanLab Strength Tester (Mesdan S.p.A., Puegnago del Garda, Italy) according to ISO 13934-1:1999 [22]. The test length was 100 mm at a deformation speed of 100 mm/min and a load of 2 N.

Table 1 shows the composition of the Ap I and Ap II baths.

Table 1. Table of the contents of baths Ap I and Ap II.

Ap I		Ap II	
APYROL CEP ECO	400 g/l	EXOLIT OP 550	400 g/l
TUBICOAT FIX HT	70 g/l	Citric acid (CA)	50 g/l
H_3PO_4	30 g/l	Sodium hypophosphite (SHP)	25 g/l
Felosan RG-N	1 g/l	Chitosan	10 g/l

2.2 Results and Discussion

The results of the measurements of breaking force, elongation at break and time to break for the untreated samples and for the samples treated with Ap I and Ap II, which were then subjected to the washing cycle, are shown in Table 2.

Table 2. Results of breaking force and elongation at break determination before and after the washing process for untreated, treated (Ap I, Ap II) and once-washed samples (Ap I_1W, Ap II_1W).

	Untreated			Ap I			Ap II		
$\bar{x}$	Fp [N]	εp [%]	t [s]	Fp [N]	εp [%]	t [s]	Fp [N]	εp [%]	t [s]
warp	1099	15,6	9,37	984,3	19,1	11,44	952,7	16,9	10,13
weft	639	17,2	10,33	595,3	19,1	11,43	553	22,1	13,27
	Untreated_1W			Ap I_1W			Ap II_1W		

warp	1060,3	15,7	9,4	938,6	17,8	10,7	946,3	17,4	10,4
weft	584	16,1	9,6	584	17,6	10,5	567,6	20,2	12,1

The results of the mechanical properties test show that the applied treatments (Ap I and Ap II) lead to a reduction in breaking force and elongation in the warp direction compared to the untreated sample, resulting in a slight decrease in fabric strength. This reduction in warp breaking strength is probably due to the low pH value of the treatment bath, which can contribute to damage to the cotton component of the fabric. The strength in the weft direction decreases only slightly, while the elongation at break increases slightly, which also indicates a slight degradation of the cellulose component. After the wash cycle, the values for breaking strength and elongation of the samples decrease only slightly, which indicates that the treatments have not significantly affected the mechanical properties of the fabric.

The results of the thermogravimetric analysis are shown in Figures 1, 2, 3, 4 and 5.

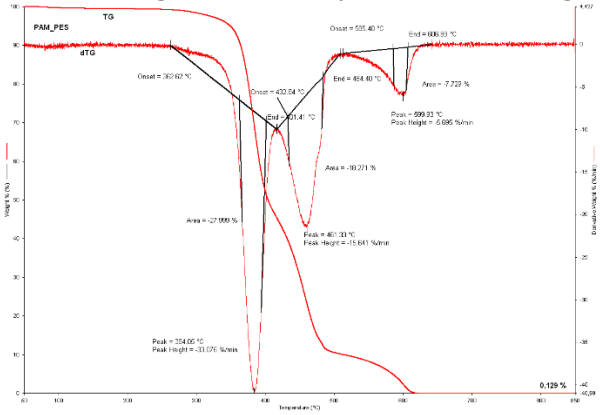

Figure 1. TG and dTG curves of the untreated sample.

Figure 1 shows the TG and dTG curves of the untreated sample, from which it can be seen that thermal decomposition takes place in three different stages. The first stage takes place at 384.05 °C with a mass loss of 33.076%/min, which corresponds to the dehydration of the sample. The second stage takes place at 461.33 °C with a mass loss of 15.641%/min, which indicates the decomposition of the sample. In this area, glucose units are broken down and volatile gases are formed in cotton, while esters are broken down and aromatic compounds are formed in polyester. [23]. The third stage is observed at 599.93 °C with a mass loss of 5.695%/min, indicating the cleavage of the polymer chains and the formation of a carbonaceous residue. The final residue is only 0.129% of the initial mass, indicating complete combustion and a lack of thermal stability of the untreated sample.

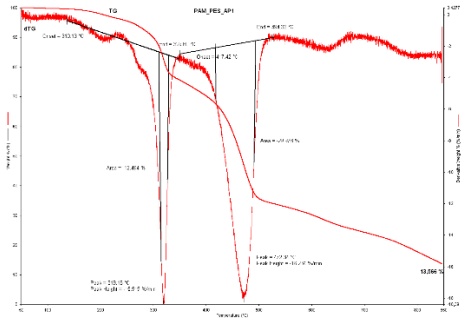

Figure 2. TG and dTG curves of the Ap I sample.

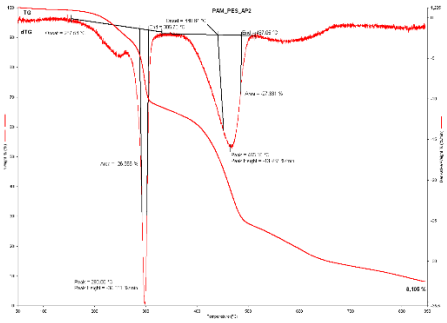

Figure 3. TG and dTG curves of the Ap II sample.

The thermogravimetric (TG) curves and their first derivatives (dTG) for the treated samples Ap I and Ap II (Figures 2 and 3) clearly show that decomposition takes place in two stages. In the first stage of dynamic degradation, water (both free and crystalline) is released at 319.16 °C for Ap I and at 298.06 °C for Ap II. In the second stage of degradation, mass loss was observed at 472.34 °C for Ap I (16.234%/min) and at 465.16 °C for Ap II (13.937%/min). This degradation profile indicates degradation of the treated polyester/cotton structure in both samples. The residue remaining after thermal degradation was 13.566% of the initial mass for Ap I and 8.105% for Ap II, indicating increased thermal resistance compared to the untreated sample.

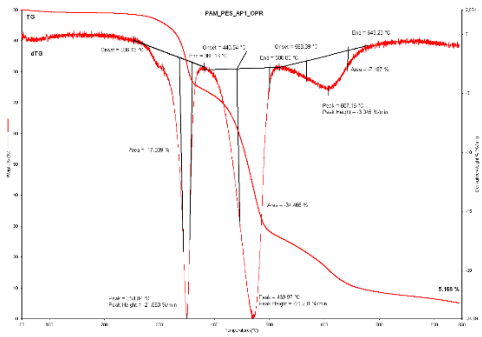

Figure 4. TG and dTG curves of the Ap I sample after the washing cycle.

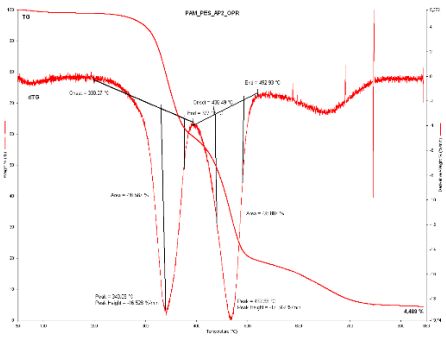

Figure 5. TG and dTG curves of the Ap II sample after the washing cycle.

The thermogravimetric (TG) curves obtained and their first derivatives (DTG) show that the decomposition of the Ap_1W sample (Figure 4) takes place in three stages, while the decomposition of the Ap II_1W sample (Figure 5) takes place in two stages. At a temperature of 350.07 °C for Ap I_1W and 340.05 °C for Ap II, the first stages of dynamic degradation were recorded. In the second stage, the dynamic degradation of the Ap I_1W sample occurs at 469.97 °C with a mass loss of 21.201%/min (Figure 4), while the Ap II_1W sample is degraded at 469.33 °C with a mass loss of 17.349%/min

(Figure 5). The third degradation phase of the Ap I sample takes place at 607.16 °C with the cleavage of the polymer chain and the formation of a carbonised residue with a mass loss of 3.045%. The residual mass of the Ap_1W sample is 5.168% and that of the Ap II sample is 4.489%, in each case based on the initial mass. The Ap I_1W sample has a lower thermal resistance than the treated but unwashed sample, but a higher thermal resistance than the untreated sample, while the Ap II_1W sample has a lower thermal resistance than the unwashed sample, but a better thermal resistance than the untreated sample.

3. Conclusion

The results of this study show that environmentally friendly textile finishing methods using "green chemistry" can provide the desired functional properties, in particular improved heat resistance, while reducing the negative impact on the environment. Samples treated with two types of finishing formulations showed differences in the effectiveness and durability of the treatment.

Treated and once-washed samples showed a decrease in tensile strength and elongation in the warp direction, while strength in the weft direction remained largely unchanged and elongation at break increased slightly.

The thermogravimetric analysis revealed a higher thermal resistance in the sample treated with Ap I, while Ap II showed a slightly lower thermal resistance and a smaller decrease in thermal stability after the care process. Ap I, which contained the organophosphorus compound Apyrol CEP ECO, showed satisfactory thermal stability, while Ap II, which contained Exolit OP 550 and chitosan, showed some problems in terms of stability and homogeneity of the coating. Nevertheless, both finishes contributed to improving the heat resistance of the material. Based on the results presented, we conclude that the use of more environmentally friendly agents (halogen-free organophosphorus compounds and chitosan as a biodegradable polymer) to achieve the heat resistance of polyester/cotton fabrics ensures the desired functionality while reducing the negative impact on the environment.

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Dynamic 3D Deformations Analysis of Human Body in Motion

Maja Mahnic Naglic and Slavenka Petrak

University of Zagreb Faculty of Textile Technology, Zagreb, Croatia

E-mail: maja.mahnic@ttf.unizg.hr

Abstract. The paper presents the analysis of dynamic deformations on the human body in motion using the optical 3D measurement system Aramis. The main purpose of the Aramis system is the analysis of dynamic deformations of objects and assemblies in the field of mechanical engineering and civil engineering. The presented research includes defining a methodology for recording and analyzing the human body in motion with application in clothing design and engineering for the first time. The measurement capabilities were tested on five body movements, highlighting the significant advantages of 3D surface deformation analysis compared to linear measurement, and demonstrating the possibilities of applying measurement results in the process of digital clothing design.

1. Introduction

Research in dynamic anthropometry is most commonly applied in the development of functional garment models designed for special purposes, particularly to define parameters for pattern adjustments during the garment construction process [1–3]. These applications are primarily directed toward the design of protective and sportswear [4,5]. Accordingly, case studies are typically conducted on individual subjects or small, targeted sample groups, depending on the garment's intended function. In such studies, body movements and deformations are analysed in postures associated with the target activity. The methods for determining measurements, the number of postures analysed, and the selection of characteristic measurements for each posture vary significantly across studies [6–8]. The methodology for obtaining body measurements in dynamic anthropometry remains insufficiently defined, both regarding activity-specific body positions and the identification of characteristic dimensions.

In the field of dynamic anthropometry, 3D body scanners are employed to capture body dimensions in various activity-specific positions, thereby enabling comparisons between standard upright posture and functional positions. From the perspective of locomotion biomechanics, these scanning positions correspond to key phases in the kinematic chain of a given movement, marked by shifts in specific body segments. To enhance accuracy of analysis, markers are often placed on anatomical landmarks prior to scanning [5–8]. A review of the literature reveals significant variation in approaches

to analysing dimensional changes in different postures, largely influenced by the intended application of the results. Although certain positions frequently appear in studies, the selection of characteristic measurements and the methods used to determine them often differ depending on the garment design objective. One of the significant advancements and the practical utility of the research findings in the practical application of dynamic anthropometry have been made within the framework of the German sizing standard SizeGERMAN, which includes a sizing system incorporating functional measurements, referring to dimensions captured in specific postures using 3D body scanning [9]. 3D scanning in fixed positions does not fully represent the human body under actual dynamic conditions. During scanning, the body's muscular activity is primally directed toward maintaining posture and balance rather than performing motion, resulting in deformations that differ from those occurring during real movement [10]. In this regard, the last decade has seen significant progress through the development of fast stereophotogrammetric 3D scanning systems, enabling sequential image capture of the body in motion—a technique referred to as 4D scanning in the literature. This technology supports comprehensive research in dynamic anthropometry by allowing the analysis of full-body motion and deformation over time [11-13]. As an alternative to 4D scanning, the present study proposes the use of an optical 3D measurement system for dynamic deformations analysis Aramis [14]. While this system has been widely validated in fields such as mechanical engineering, civil construction, and manufacturing, its application within dynamic anthropometry remains unexplored.

2. Test subjects and Methods

2.1 Selection of female test subjects according to body type

Using the laser 3D scanner Vitus Smart, Human Solution GmbH, Germany, a sample of 126 adult female participants aged between 20 and 40 years was scanned, following ISO standard 20685 [15]. Body measurements necessary for classifying body types in the frontal plane were determined from the scanned 3D models using the Anthroscan software, as shown in Figure 1. The method for classifying body types in the frontal plane is based on the relationship between six body width measurements in characteristic areas such as shoulders, chest, waist, and hips, and six corresponding heights measured from the ground in a standing position, which describe the shape of the lateral body curve in the frontal plane, Figure 1 [16].

Through statistical cluster analysis, three body types were identified within the sample and three participants who best matched the identified characteristics of each body type were selected for further research on surface deformation in dynamic movement conditions, Figure 2. Body type F1 is characterized by almost equal widths of the body in the chest, waist, and hip areas, with very slight inclinations of the lateral body curve, which significantly distinguishes this body type from the other two. Body

types F2 and F3 have a pronounced waist and curved lateral body curves, differing in the curvature shape in the lower body area, between the waist and hips. Body type F2 is characterized by a gentler curve at the waist-to-hip transition and a specific flat triangular shape of the lower body, while body type F3 has a more pronounced curve at the waist-to-hip transition and a rounded lateral body curve, Figure 2.

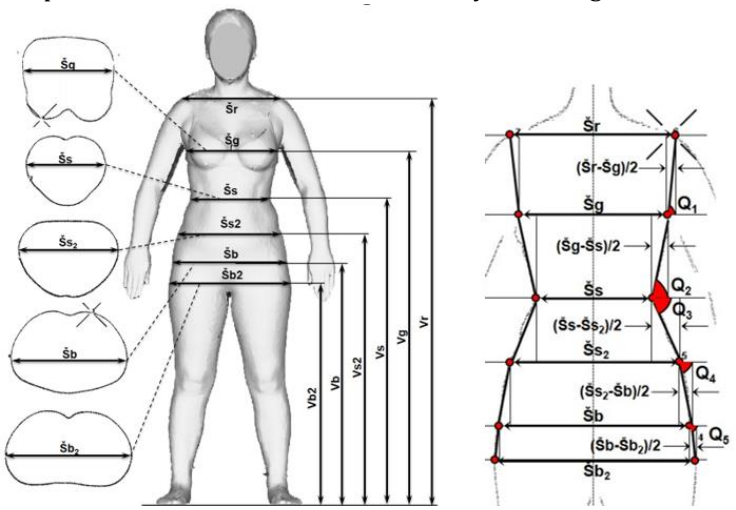


Figure 1. Methodology for the classification of female body types according to the shape of the lateral curve in the frontal plane [16].

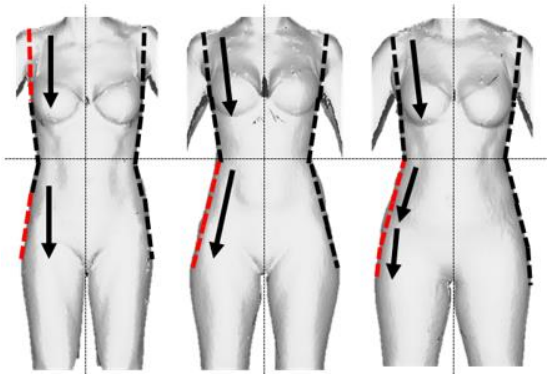


Figure 2. Selected representatives of female body types for further analysis [16].

2.2 Body Movement Recording Using the Aramis Optical 3D Measurement System for Dynamic Deformations Analysis

Using the optical 3D measurement system for dynamic deformations analysis Aramis, four predefined body movements were recorded on the three selected participants of different body types (I1, I2, and I3), with the final positions corresponding to characteristic body positions P1 to P4, Figure 3.

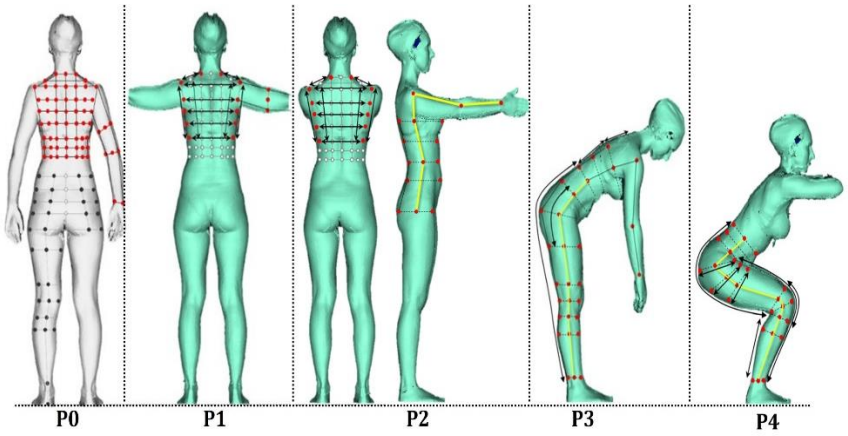


Figure 3. Four characteristic body positions for deformation analysis

Following the Aramis system methodology, a black stochastic dot pattern was manually applied to the participants' bodies, dressed in tight-fitting sports undergarments, using body paint. Black-and-white circular markers were placed on anthropometric reference points to ensure precise positioning of points during the later processing of measurement surfaces and deformation analysis, Figure 4. Four kinematic chains of movement, covering four characteristic positions, were recorded in the posterior and sagittal planes, Figure 5.

Figure 4. Preparing subjects for Aramis recording

The processing of recorded results and geometric 3D surface deformation analysis during the movements was performed using GOM Inspect Suite 2020 and ZEISS Inspect Correlate v.2023 [15]. The processing included creating 3D body surfaces for analysis and segmentation of surface areas based on movement and the zones being analysed, as well as adapting the coordinate system of each surface segment, Figure 6. For the creation of 3D measurement surfaces, additional points (facets) were generated to obtain higher-quality geometry for analysis. The coordinate system for each body

segment was adjusted according to the typical direction of textile thread orientation in garments, allowing the deformation analysis and determined parameters to be related to clothing design and pattern modifications necessary for achieving high garment fit under dynamic conditions.

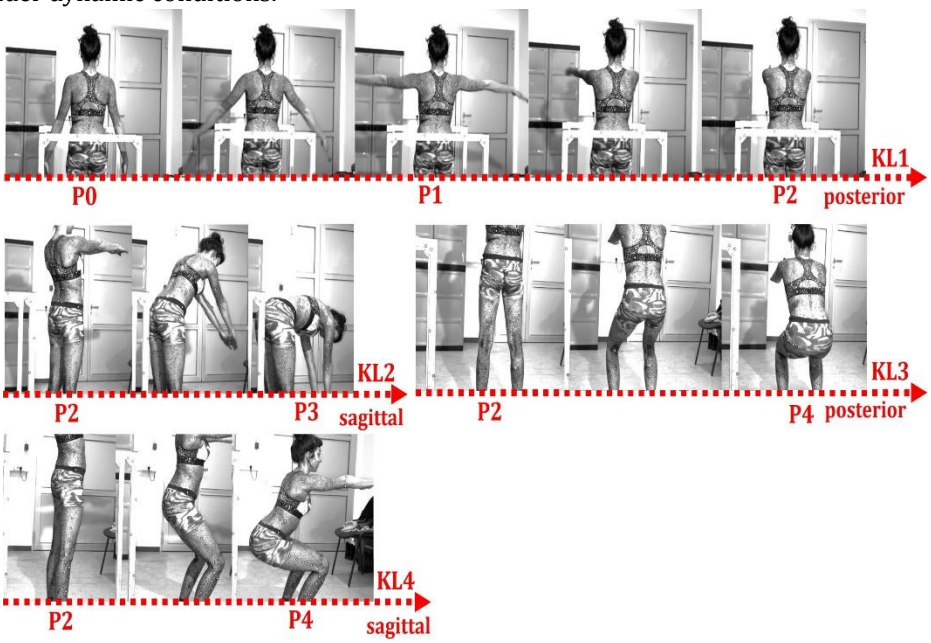


Figure 5. Defined kinematic chains of movement

Due to the observed deficiencies in measurement surfaces on the lower body caused by the coverage of hip and buttock areas by underwear, and given that the most significant changes were expected in these areas during forward bending (P3) and squatting (P4) movements, the deformation analysis of the body in movements KL3 and KL4 included recording and analyzing participants dressed in tight-fitting jumpsuits, specifically tailored to their individual body measurements and characteristics. The jumpsuits were made from knitted fabrics with a high elastane fiber content, and the stochastic dot pattern was applied to the material using digital printing techniques.

For precise analysis and monitoring of surface geometry deformations by zones in each movement, networks of curves were created on the recorded 3D measurement surfaces using transverse and sagittal cross-sections along lines of characteristic body circumferences and dimensions. The positions of cross-sections and curves for each participant were determined based on measurements obtained from 3D scanning.

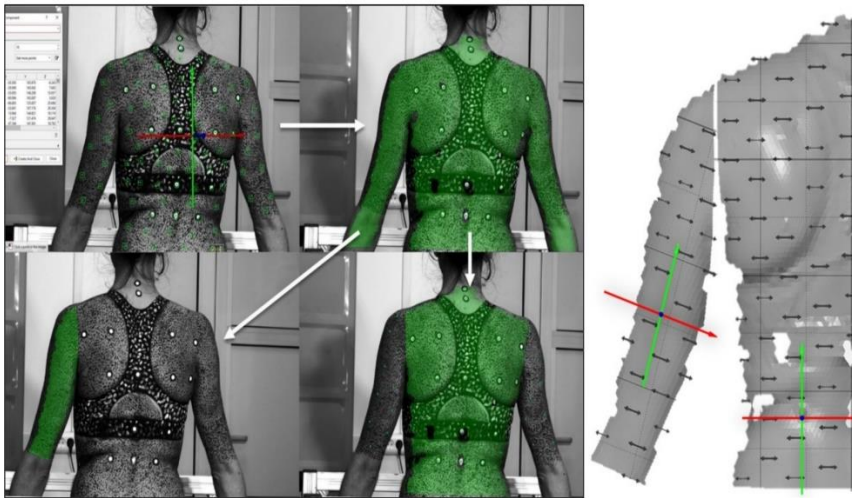


Figure 6. Creation of the measurement surfaces and adjustment of the segment coordinate system segments

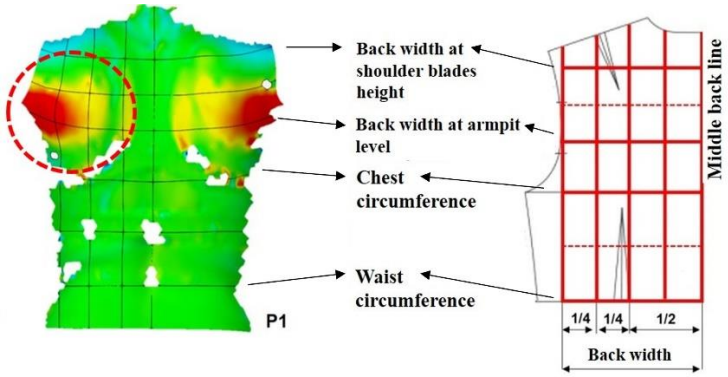


Figure 7. Grid of curves for the precise analysis of deformations by zones

2.3 Analysis of Body Deformations in Characteristic Positions

In each of the four characteristic positions, deformations in the transverse and longitudinal directions of the body surface were analysed, and zones of maximum deformation were identified for each of the three participants. Based on the identified zones, surface segments were created, and the analysis determined the maximum deformation values expressed as the mean deformation values of each segment in a given direction, expressed as percentages, Figure 8.

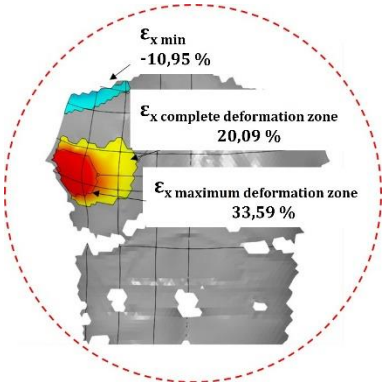


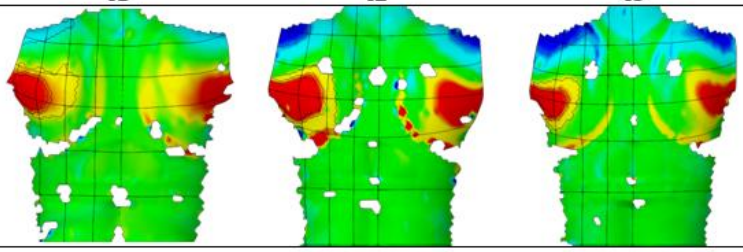
Figure 8. Analysis of maximum deformation zones

3. Results

3.1 Results of Body Deformation Analysis in Positions P1 and P2

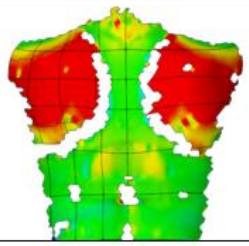
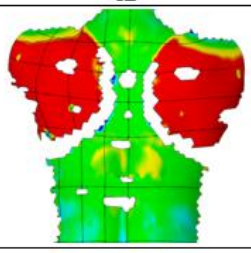
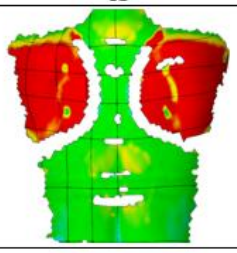
During arm movements, analysis of surface deformations in final positions P1 and P2 revealed significant transverse deformations in the back area. The maximum deformation values of the surface segments are shown in Tables 1 and 2. Observing the rectangular grid of characteristic lines on the body, the zone of maximum deformation extends along the back width line at the armpit level. From the transverse cross-sections, in position P1, deformation increases from the posterior line, where deformation is almost absent, towards the lateral lines, with maximum deformation in the second quarter of the back width. Negative deformation is observed across the entire shoulder width, extending to the line at the scapula level, Table 1.

Table 1. Results of the transverse deformations analysis in the open-arm position (P1) on three female subjects with different body types.

P1	I1	I2	I3
ε_x			
$\varepsilon_{x\,max}$ [%]	33,59	27,71	23,33
$\varepsilon_{x\,min}$ [%]	-11,24	-16,00	-14,88

In position P2, transverse deformations are observed across the entire back surface, from shoulder height to the chest circumference, Table 2. The highest value of 37.39% was recorded for participant body type I2.

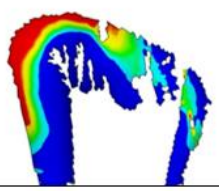
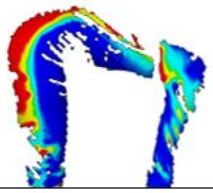
Table 2. Results of the transverse deformations analysis in the arms-forward position (P2) on three female subjects with different body types

P2	I1	I2	I3
ε_x			
$\varepsilon_{x\,max}$ [%]	34,54	37,39	30,48

3.2 Results of Body Deformation Analysis in Position P3

In position P3, analysis of surface deformations in the posterior body area revealed significant longitudinal (y-direction) deformations along the length from the chest circumference to the knee circumference and along the posterior leg length from the hip circumference to the thigh circumference. The identified zones and maximum deformation values for each of the three participants are shown in Table 3.

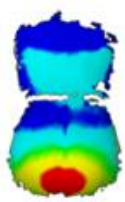
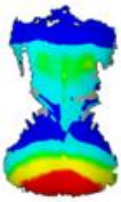
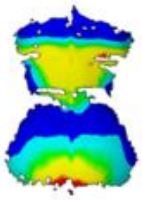
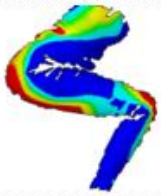
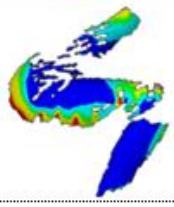
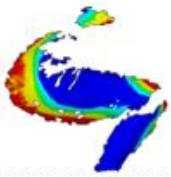
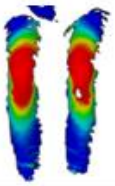
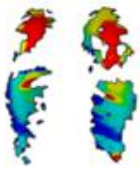
Table 3. Results of the longitudinal body deformations analysis in the forward bend position (P3) on three subjects of different body types, in the sagittal plane

P3	I1	I2	I3
ε_y			
$\varepsilon_{y\,max}$ [%] Og - Os	21,83	23,93	25,68
$\varepsilon_{y\,max}$ [%] Os - Ob	23,93	24,21	23,94
$\varepsilon_{y\,max}$ [%] Ob - Onk	25,04	23,94	20,33

3.3 Results of Body Deformation Analysis in Position P4

In the movement of lowering the body into a squat position (P4), in addition to longitudinal deformations along the length from the waist circumference to the thigh circumference, the transverse deformation zone in the hip area was also analysed. The maximum deformation values of the surface segments for each of the three participants are shown in Table 4.

Table 4. Results of the longitudinal body deformations analysis in the squat position (P4) on three subjects of different body types

P4	I1	I2	I3
ε_x			
ε_y			
			
$\varepsilon_{x\,max}$ [%] – hips	19,21	18,60	16,05
$\varepsilon_{y\,max}$ [%] Os - Ob	21,11	21,22	23,58
$\varepsilon_{y\,max}$ [%] Ob - Onk	23,16	19,71	20,98
$\varepsilon_{y\,max}$ [%] - knee	25,70	27,94	29,76

4. Conclusions

The application of the optical 3D system for dynamic analysis of deformations, Aramis, enabled the recording and detailed analysis of body deformations during movement,

where surface geometry deformations were analysed in specific directions (x/y), depending on the observed body segment. The ability to monitor deformations throughout the entire movement execution and to visualize and analyse surface segments affected by deformation represents a significant advantage compared to 3D body scanning in characteristic positions and determining linear changes in body dimensions.

Using the 3D measurement system Aramis for analysing surface geometry deformations in three participants of different body types, different values and zones of body deformation were identified for each movement. Although all three participants shared similar body measurements, with basic body measurements corresponding to the same clothing size (size 38), the observed differences in deformations can be attributed to belonging to different body shape types. The defined methodology of zone-based analysis, determined by a network of characteristic body curves, supports the integration and application of research results in clothing design and the development of new models that ensure high garment fit under dynamic conditions.

Based on the current findings, future research will aim to extend the application of the optical 3D measurement system Aramis to more complex and dynamic body movements, such as jumping and running. This will provide further insight into the behaviour of body surface deformations under high-intensity and rapid motion conditions, thereby expanding the understanding of dynamic fit requirements in functional garment design. Moreover, the methodology developed for zone-based deformation analysis, defined through a network of characteristic body curves, will be further refined and applied across a broader sample of participants with varying body shapes and sizes. This will enable a more comprehensive evaluation of individual variability in deformation patterns, contributing to the development of advanced sizing systems and improved personalization in garment construction. In parallel, ongoing efforts will focus on integrating deformation data with material characteristics, especially with respect to tensile properties, to improve material selection strategies in terms of meeting the high demands of dynamic fit. The long-term goal is to translate these insights into the design of garments with optimized fit, comfort, and functionality for specific use cases, including sportswear, workwear, and medical clothing.

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Frieze Symmetry Groups in Stapar Kilims: From Traditional Weaving to Mathematical Classification

Branka Janković[1] and Marija Pešić[2]

[1] Visoka škola za obrazovanje vaspitača, Novi Sad, Serbia
[2] University of Novi Sad, Technical Faculty "Mihajlo Pupin", Zrenjanin, Serbia

E-mail: marija.pesic@tfzr.rs

Abstract. This paper analyzes the linear patterns of the indigenous Stapar kilim from the perspective of geometric symmetry. The examined patterns emerge through the repetition of symmetric or asymmetric motifs, all exhibiting translational symmetry, while additional symmetry transformations—vertical reflection, horizontal reflection, rotation of order 2, and glide reflection—may optionally be present. The aim of this study is to formalize the mathematical concept of symmetry in the context of frieze patterns found in the Stapar kilim. Through the analysis and classification of these friezes, the paper presents methods for constructing the corresponding symmetry groups. These findings provide designers with a structured foundation for artistic exploration, enabling them to develop new design approaches through variations in patterns, compositional strategies, and different methods of motif repetition. The analysis of historical samples reveals that all seven possible frieze symmetry groups are present in Stapar kilims, with some symmetry groups occurring at significantly lower frequencies.

1. Introduction

The mathematical concept of symmetry has been present in art since the Paleolithic and Neolithic periods [6]. Symmetry undeniably goes beyond the boundaries of mathematics; among other applications, it is evident in the creation of decorative design within the textile industry [4]. Day [2] argued that the beauty of a design lies not so much in the nature of the individual elements from which it is composed, but rather in the manner of their arrangement—specifically, in the repetition of elements to form a new structure. Naturally, there are various ways to repeat a basic element, and geometric principles allow for the analysis and classification of designs created through such repetition. In the 1930s, Woods [13] was the first to publish research presenting the principles of geometric symmetry found in design patterns—mathematicians call them rosette, frieze, and plane tiling. Horne [4] discusses in detail the significance of employing geometric symmetry in design and emphasizes that artists intuitively perceive symmetry and that it is inherently present in their work. However, Horne [4]

also notes that the application of the mathematical concept of symmetry enables a systematic approach that reveals all possible combinations of symmetrical structures, which can serve as a starting point for further artistic exploration.

Symmetry is frequently studied from both historical and cultural perspectives, particularly in the analysis of ornamentation within traditional cultures [6]. The ornamental heritage of Vojvodina's folklore is notably rich, and this paper focuses on the exploration of folkloric motifs found in woven kilims. Vojvodina, as a multiethnic region, encompasses a diverse range of communities whose distinct approaches to kilim weaving are reflected in their unique use of colour and ornamentation. At the end of the 19th and the beginning of the 20th century, the most prominent kilim-weaving centers in Vojvodina included Melenci and Kumane in the Banat region, known for promoting the so-called Torontal kilim; Stapar in the Bačka region, recognized for the Stapar kilim; and the Srem region, which developed its own kilim tradition characterized by specific ornamentation and colour [9].

In this study, we will analyze and classify linear patterns found in the Stapar kilim, without diminishing the significance of the ornamentation present in other kilim-weaving traditions of Vojvodina. The classification method employed for linear design is based on frieze symmetry groups and relies both on the geometric properties of the overall design structure and on the symmetry of the individual motifs that constitute the design. Naturally, the symmetry of the individual motifs influences the overall symmetry of the design.

2. Stapar kilim

Stapar kilim weaving dates back to the 18th century and developed in the village of Stapar, located in the Bačka region in the northwestern part of Vojvodina. The weaving technique employed is known as the **klečanje** technique, which produces kilims with two identical sides—meaning there is no reverse side [11]. When folded into four equal parts, the kilim reveals identical quarters, indicating that the overall composition possesses both vertical and horizontal axes of reflection. The ornamentation of the Stapar kilim may be geometric or figural (floral, zoomorphic, or anthropomorphic motifs). As a decorative element, angular “spikes” in the shape of triangles are often found along the shorter edges of the kilim, and a distinctive feature of the Stapar kilim is the absence of fringes. Until the 1920s, natural vegetable dyes were used in Stapar for colouring wool yarn, even though synthetic aniline dyes had already become predominant in other parts of Vojvodina [9].

In the second half of the 19th century, weavers in Stapar organized themselves in such a way that some specialized in kilim weaving, while others were responsible for selling the kilims in Italy, Dalmatia, and Dubrovnik. These women brought back new patterns, and weaving techniques from abroad, and among them were those who also created original designs. Ornamentation was also transmitted through the visual exchange of patterns among groups of weavers. This was followed by a period in which

motifs were adopted from fashion magazines, leading to the popularity of kilims featuring large wreaths, roses, and peonies [9]. The tradition of kilim weaving is still maintained in the village of Stapar today. These kilims are particularly known for the motif of the "Stapar rose" and have been included in the intangible cultural heritage of Serbia.

During the period from the second half of the 19th century to the first half of the 20th century, several types of kilims were produced simultaneously: striped kilims; kilims with infinite patterns; kilims with a border; kilims with a border and a central field; kilims with a border, a central field, and a central medallion. Table 1 presents examples of Stapar kilims on which the frieze symmetry groups analysed in this study have been mapped. The first two kilims are representatives of the striped type. In the third kilim, both the border and the central field are evident. The fourth and fifth kilims feature a border, a field, and a medallion, with floral motifs dominating the composition. The sixth kilim, like the previous two, contains a border, field, and medallion, but differs in that it was woven on a wide loom. Although it also features floral ornamentation, the motifs were adopted from factory-made bedspreads or printed materials, meaning they do not belong to the traditional ornamental vocabulary [5, 9].

Table 1. Stapar kilims

1. Stapar, Bačka, Museum of Vojvodina [5]	2. Stapar, Bačka, Museum of Vojvodina [5]	3.Stapar, around1870., Bačka, Museum of Vojvodina [5]

4. Stapar, Bačka, around 1890., Museum of Vojvodina [9]

5. Stapar, Bačka, around 1895., Museum of Vojvodina [9]

6. Stapar, Bačka, 1915-1920, Museum of Vojvodina [9]

3. The mathematical concept of a frieze symmetry groups

In ornamental art, friezes are finite horizontal linear patterns, whereas in the mathematical sense, a frieze is defined as an infinite linear pattern that exhibits the properties of a group symmetries Sym(x): closure, associativity, the existence of an inverse element, and the existence of an identity element with respect to the binary operation of composition of isometric transformations [12]. A frieze is invariant under translation along the translation axis and does not contain invariant points. In addition to translation, the generators of a frieze symmetry group may include the following isometric transformations: reflection (either vertical or horizontal), glide-reflection, and two-fold rotation (Figure 1).

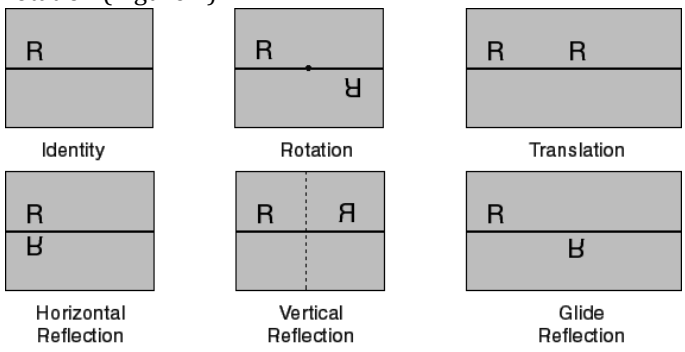
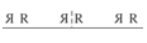
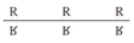
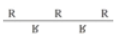
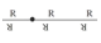


Figure 1. Isometric transformations, adapted from [10]

By composing the four types of isometric transformations that may serve as generators of frieze symmetry groups, seven distinct frieze symmetry groups are formed. In the literature, the notation most commonly used for these groups is of the form **pxyz**. The symbol **x** denotes the presence or absence of a isometric transformation orthogonal to the translation axis: it is written as **1** if vertical reflection is absent, and as **m** if vertical reflection is present. The third symbol **y** represents an isometric transformation parallel to the translation axis: **1** indicates the absence of horizontal reflection, **m** denotes the presence of horizontal reflection, and **g** denotes the presence of a glide-reflection. The fourth symbol **z** denotes the presence or absence of a two-fold rotation: it is written as **1** if such a rotation is absent, and as **2** if it is present [1]. Using this notation, the seven frieze symmetry groups are expressed as follows: **p111**, **p112**, **pm11**, **p1m1**, **pmm2**, **pmg2**, and **p1g1**.

In the process of classifying ornaments into frieze symmetry groups (Table 2), the presence of vertical reflection, horizontal reflection, and finally, two-fold rotation, is determined.

Table 2. The method for classifying frieze patterns into symmetry groups, adapted from [8]

VERTICAL REFLECTION						
YES			NO			
HORIZONTAL REFLECTION			HORIZONTAL REFLECTION OR GLIDE-REFLECTION			
YES	NO		YES		NO	
	TWO-FOLD ROTATION		HORIZONTAL REFLECTION		TWO-FOLD ROTATION	
	YES	NO	YES	NO	YES	NO
pmm2	pmg2	pm11	p1m1	p1g1	p112	p111
						

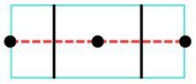
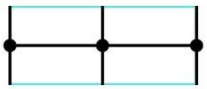
4. Research method

For the purposes of this research, friezes from a sample of 30 Stapar kilims, woven between the second half of the 19th century and 1955, were analyzed. Photographs of kilims from the Ethnological Department collection at the Museum of Vojvodina served as the source material [5, 9]. The aim of the research was to analyze and classify the frieze patterns on Stapar kilims into the appropriate symmetry group and to present methods for constructing the corresponding symmetry groups. Each approximately symmetric frieze of a Stapar kilim was considered symmetric, disregarding details and colour.

5. Research results and discussion

A frieze in ornamental art, as a finite linear pattern, is created by translating a motif along the translation axis. The motif of a frieze may be asymmetric or symmetric, with a symmetric motif consisting of two or more units that are asymmetric, yet of the same size, shape, and content [3]. In the analysis and classification of a frieze into a symmetry group, it is essential to map the motif on the given frieze and identify the presence of isometries that leave the motif invariant. Table 3 shows the isometric transformations that maintain the invariance of the frieze motif, depending on the symmetry group [4].

Table 3. The symmetry properties of frieze motifs

Friz	Isometric transformations	Frieze motif
p111		
p1g1	glide-reflection	
pm11	vertical reflection	
p112	two-fold rotation	
pmg2	vertical reflection glide-reflection two-fold rotation	
p1m1	horizontal reflection	
pmm2	vertical reflection horizontal reflection two-fold rotation	

In the following section of the paper, the properties and construction of friezes are first presented through a well-known examples from the literature according to [1, 3, 8, 12]. Subsequently, for each frieze symmetry group, an example of a Stapar kilim frieze is provided.

5.1. The frieze symmetry group of type p111

The frieze symmetry group of type p111 is generated only by translation. The frieze motif is asymmetric and does not possess two-fold rotational symmetry, reflection

symmetry, or glide-reflection symmetry. Figure 2 shows an example of a p111 frieze, where the asymmetric motif is represented by the upright letter R, and the distance between two consecutive R's corresponds to the length of the shortest translation vector. The frieze remains invariant under a translation to the right by the length of the translation vector, as well as under a translation to the left by the same length.

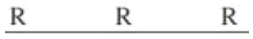


Figure 2. Frieze pattern p111

An example of such a pattern can be found on a striped Stapar kilim from 1905. The motif represents a zoomorphic ornament—a stylized hen—that is asymmetric and repeats translationally (Figure 3).

Figure 3. Frieze pattern p111 on the Stapar kilim

5.2. The frieze symmetry group of type p1g1

The generator of the p1g1 frieze symmetry group is a glide-reflection. A glide-reflection is a composition of reflection and translation along a direction parallel to the axis of reflection. A figure possesses a glide-reflection if a part of it is first translated and then reflected across the axis of reflection. The motif of the p1g1 frieze is symmetric, meaning it is invariant under glide-reflection. Figure 4 shows the construction of the p1g1 frieze, where it is noticeable that the length of the translation vector differs from the length of the glide reflection vector. The frieze motif consists of two units: the upright letter R and the inverted letter R. This motif is then periodically repeated through translation to the right by the length of the translation vector. The length of the shortest translation vector corresponds to the distance between two consecutive motifs, and in our example, it is equal to the distance between two consecutive upright letters R.

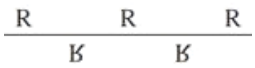


Figure 4. Frieze pattern p1g1

An example of such a pattern was mapped on only one Stapar kilim from 1890. The motif of the kilim, which repeats translationally, is marked by a blue rectangle, and the axis of glide reflection is indicated by a dashed red line (Figure 5).

Figure 5. Frieze pattern p1g1on the Stapar kilim

5.3. The frieze symmetry group of type pm11

The frieze symmetry group of type pm11 is generated by translation and vertical reflection. The frieze motif, which is translated along the translation axis by the length of the shortest translation vector, is symmetric with respect to the vertical reflection axis. The reflection axis is orthogonal to the translation axis. Figure 6 shows the pm11 frieze. The motif consists of two units: the upright letter R and its reflection with respect to the vertical reflection axis. The distance between two consecutive vertical reflection axes is equal to half the length of the shortest translation vector.

Я R Я R Я R

Figure 6. Frieze pattern pm11

An example of the pm11 frieze pattern can be found on a Stapar kilim dating from the period 1915-1920. The motif of the kilim, which repeats translationally, is marked by a blue rectangle, and the reflection axes are indicated by vertical lines (Figure 7).

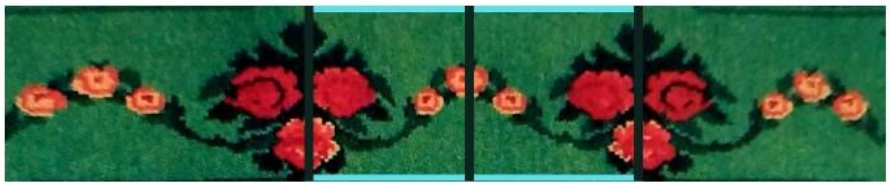


Figure 7. Frieze pattern pm11 on the Stapar kilim

5.4. The frieze symmetry group of type 112

The frieze symmetry group of type p112 is generated by translation and two-fold rotation, while reflection and glide-reflection are not present in this frieze. Figure 8 shows the p112 frieze pattern. The motif of the frieze consists of two units: the upright letter R and its image obtained by rotating the upright R by 180 degrees about the center of rotation, which is located on the translation axis and between the upper and lower R letters. The second center of rotation is also located on the translation axis, in the middle between two consecutive upright R letters. It is important to emphasize that the center of rotation is an invariant point, and the 180-degree rotation is called a half-turn. The length of the shortest translation vector is twice the distance between two consecutive centers of rotation.

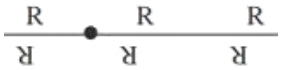


Figure 8. Frieze pattern p112

Figure 9 shows a frieze that possesses two-fold rotational symmetry and translational symmetry, and it is found on the "Green Kilim with Grapevine" dating around 1895. The motif of the frieze is marked in blue, and the two-fold centers of rotation are indicated by black dots.

Figure 9. Frieze patternp112 on the Stapar Green Kilim with Grapevine

5.5. The frieze symmetry group of type pmg2

The symmetry group of type pmg2 is generated by glide-reflection and two-fold rotation. Vertical reflection is a composition of glide-reflection and two-fold rotation, and therefore, the symmetry group pmg2 possesses translational symmetry, vertical reflection, glide-reflection, and two-fold rotation. In the pmg2 frieze pattern, the length of the translation vector differs from the length of the glide-reflection vector (Figure 10). The motif consists of four units: upright letter R, reflected R, inverted letter R, and its reflection. The centers of two-fold rotation are located at the midpoint of the distance between the vertical reflection axes.

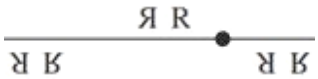


Figure 10. Frieze pattern pmg2

Figure 11 shows the pmg2 frieze on the "Green Kilim with Grapevine" dating around 1895. The motif of the frieze, which repeats translationally, is marked by a blue rectangle, the vertical reflection is indicated by a gray line, the glide reflection axis is marked by a red line, and the two-fold rotation centers is marked by a black dots.

Figure 11. Frieze pattern pmg2 on the Stapar Green Kilim with Grapevine

5.6. The frieze symmetry group of type p1m1

The frieze symmetry group p1m1 is generated by translation and horizontal reflection. Figure 12 shows the symmetry group p1m1. The motif of the frieze consists of two units: upright letter R and inverted letter R. The motif is translated to the right by the length of the translation vector, which is equal to the distance between two consecutive upright R letters.

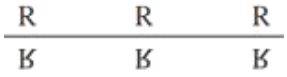


Figure 12. Frieze pattern p1m1

An example of the p1m1 frieze pattern (Figure 13) is mapped on a Stapar kilim dating from the second half of the 19th century. The zoomorphic motif (a stylized bird) is marked with a blue rectangle and possesses a horizontal axis of reflection.

Figure 13. Frieze pattern p1m1 on the Stapar kilim

5.7. The frieze symmetry group of type pmm2

The frieze symmetry group of type pmm2, in addition to translation symmetry, possesses vertical reflection, horizontal reflection, and a two-fold rotation. The generators of this symmetry group are translation, horizontal reflection, and vertical reflection. The two-fold rotation is obtained as a composition of the horizontal and vertical reflections. Figure 14 shows the pmm2 frieze. The motif of the frieze consists of four units: upright letter R, reflected R, inverted letter R, and its reflection.The vector of the glide-reflection is of the same length as the translation vector. The two-fold rotational center is located at the intersection of the vertical and horizontal reflection axes.

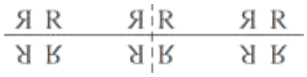


Figure 14. Frieze pattern pmm2

In Figure 15, the pmm2 frieze pattern shown is found on a kilim dating from 1870. The motif that repeats translationally is highlighted with a blue rectangle, the reflection axes are marked with black lines, and the black dot represents the two-fold rotational center.

Figure 15. Frieze pattern pmm2 on the Stapar kilim

6. Conclusions

Research on ornamentation from the mathematical aspect of symmetry began in the early 20th century and continues to attract significant interest from mathematicians who study and represent the ornamentation of various cultures. In this context, the subject of this paper is the analysis of patterns found in the Stapar kilim, created through a combination of symmetric or asymmetric motifs. By linearly combining motifs along the horizontal translation axis, with the optional presence of reflection, two-fold rotation, and glide-reflection, one of the seven symmetry groups of the frieze can be constructed.

The results of the research show that all seven frieze symmetry groups are present on Stapar kilims from the second half of the 19th century and the first half of the 20th century, with some groups, such as p112 and p1g1, being exceptionally rare. The frieze symmetry group p1g1 was mapped on only one Stapar kilim. It is interesting to note that this result aligns with the conclusion of Bodner [1], who emphasizes that the presence of glide reflection is very rare in friezes mapped on buildings in the Alhambra and Seville, as well as with the conclusion of James, James, and Root [7], who studied the frequencies of designs in European folk costumes from 73 cultures. The authors do not provide an explanation as to why the frieze symmetry group p1g1 has the lowest frequency.

Although the mathematical approach to symmetry in ornamentation research allows for the analysis and classification of symmetric structures, as well as the identification of all possible ways of their combination and can serve as inspiration for visual research and artistic creation, it does not provide an explanation for the method and reasons behind the creation of ornaments in traditional cultures. This excludes the subjectivity of the human factor, which simultaneously represents a limitation of this type of research.

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Determining the value of body measurements in the construction of women's clothing for industrial production

Ksenija Dolezal, Blaženka Brlobašić Šajatović and Renata Hrženjak

University of Zagreb Faculty of Textile Technology, Zagreb, Croatia

E-mail: ksenija.dolezal@ttf.hr

Abstract: The aim of this paper is to determine the differences in the values of selected body dimensions, important in the construction of women's clothing, obtained by mathematical calculations and empirically, during anthropometric measurements of a sample of the female population. Body dimensions, which are analyzed in the framework of this paper, are important for the industrial production of clothing because the cut of the desired garment must be made based on the clothing size, which is determined only by the main body measurements. Then, all necessary body dimensions are determined based on mathematical calculations. In the procedures for constructing clothing, these measurements are called construction measurements, and they are determined based on the laws of the relationship between the main and additional measurements, determined by mathematical calculations. In the framework of this paper, the selected body dimensions are: sleeve depth (Do), back length (Dl) and back width (Šl). The research includes three groups of women, and each group is aged from 20 to 85 years. In the first group, 895 women were measured, in the second group 1109 women and in the third age group 799 women. Descriptive statistics methods were used in the research, which includes estimating the parameters of central tendency and dispersion.

Key words. body proportions, anthropometry, women's clothing, clothing Construction

1. Introduction

Body measurements are used in clothing production, which in turn form the basis for the fit of clothing and have a direct impact on customer satisfaction and better product placement on the market. Knowledge of body measurements is obtained by carrying out systematic anthropometric studies on a representative sample of a specific population. The application of the data obtained is used in the construction and modelling of clothing, as the principles of clothing construction are based on body measurements and proportions. To create clothing patterns, it is necessary to study a large number of proportions. Proportions or ratios can establish the correct relationship between individual body parts or specific measurements. Proportions can be used to determine deviations of the body from the average physique [1]. Since clothing must provide an acceptable fit on the wearer's body, it is inevitable that attention will turn to the determination of body shape, differences in body shapes

within the population and differences between different population groups. By analyzing data from anthropometric research, parameters are obtained that form the basis for creating a system of clothing sizes. The basic names for clothing sizes represent the most important body measurements, and all measurements required for the construction of garments are determined by laws of proportion [2].

2. Proportionality of body measurements

Many philosophers and artists throughout history have studied the proportions of the various parts of the human body and then determined the laws of the relationships between the proportions. These laws are called canons and have been known since ancient times. Each of the known canons is formed by a specific module, a single dimension of the body, according to which the sizes of the other parts are determined, which can be larger or smaller than the dimensions of the module. In ancient Egypt, knowledge of three units of measurement was recorded, derived from the relationships of human body measurements. The cubit (466 mm) corresponded to the length of seven palms (66.5 mm), which in turn corresponded to the width of four fingers. Since they considered the length of the foot to be the unit of measurement for the body, the average height of a man corresponded to seven foot lengths. During the Middle Kingdom, artists developed a grid that lasted for centuries. It consisted of 18 equal squares into which the human body was shaped from the feet to the hairline (Figure 1). In later epochs, the accepted model of the human figure and the grid system changed, with the grid consisting of 20 squares. In ancient Greece, man was the measure of all things, and in Greek sculpture all sculptures were based on the harmony and balance of the individual parts and the whole of the human figure. The most famous nude figure of a youth from this period is the bronze Doriforos (the Spear Bearer) by Polykleitos (Figure 2). The proportions of the statue were determined by the ratio of the head to the height of the body (1:7) and the hand to the height of the body (1:10), while the width of the shoulders almost corresponded to the height of the torso [3]. Throughout history, many sculptors and painters have tried to unravel the mystery of beautiful esthetics, which they explained through mathematical relationships. The Roman architect Vitruvius was at the forefront of this. He pointed to symmetry and harmony in the relationship between parts and the whole. He defined the height of the head as the measure of proportions (8 head lengths corresponded to the height of the human body). Renaissance artists drew on his study of the proportions of the human body. The Renaissance marked the beginning of the study of ancient art, which had been neglected during the Middle Ages, and the return to ancient ideals that put the human being back at the center of interest. Many theorists cite Vitruvius as the source of this research [1,3]. However, the most important reflections on Vitruvius understanding of human proportions were made by Leonardo da Vinci, the Italian artist and scientist who was concerned with the general dimensions of the human figure and with considerations on the application of this knowledge. Leonardo illustrates Vitruvius work with his drawing, which explains: "The navel is naturally located in the middle of the human body. So if a man lies face up with his arms and legs spread apart and a compass centered on the navel describes a circle, his hand and foot fingers touch the contours of the circle. In addition to the circular contour, a square contour of the human body can

also be determined. If you measure the length from the feet to the crown of the head and the length of the outstretched arms, you will find that they are the same length. Based on this understanding, the human body can be described as a square [1,3].

Figure 1. Division of the human figure in the grid system [4]

Figure 2. Representation of body proportions on Polycleitus' Doryphorus [5]

Figure 3. Drawing of the Vitruvian Man by Leonardo da Vinci [6]

At the end of the 19th century, body proportions were based on the principles of the golden ratio. The golden ratio is a compositional law in which the smaller part relates to the larger part in the same way as the larger part relates to the whole [7, 8]. The determination of proportional measurements, which are of great importance for the production of clothing, is based on the rules and laws of proportion. Proportional body measurements are extremely important in the construction of clothing for industrial production, as a pattern for the desired garment must be created solely on the clothing size, which is determined only by the main body measurements. Only through calculations can its value be determined [2]. The selected parameters, the arm depth and the back width (Figure 4), are mathematically calculated based on the ratio of the bust girth. The average values of bust girth for all three groups of respondents are shown below.

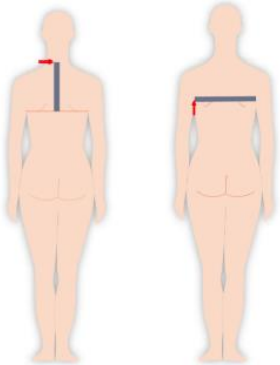

Figure 4. Body measurements: a) arm depth and b) back width

3. Material and Methods

3.1 Subjects

This research includes a sample of 895 women in I. group, 1109 women in II. group, and 799 women in III. group. The age of all respondents is between 20 and 85 years. Depending on their age, the respondents are divided into age groups of ten years, of which there are seven in total.

3.2 Methods

The measurements required for this study were carried out as part of the technological research project "Croatian Anthropometric System" of the STIRP CAS according to a standardized method. The measurements were taken with anthropometric instruments, a one-armed anthropometer and a measuring tape, in accordance with the ISO 3635, ISO 8559 and EN 13402 standards. Three body dimensions were taken from a sample of respondents: arm depth, back width and bust girth.

3.3 Statistics

The study of body measurements in a sample of the female population was carried out using methods of descriptive statistics, which include the estimation of the parameters of central tendency (mean and median) and dispersion (standard deviation, coefficient of variation, 95% confidence interval and range of the data). The results of the analyzes are presented in tabular form. The data were described and processed using the statistical packages Statistica and SPSS and with the help of specialist literature [9-10].

4. Results and discussion

The descriptive statistics method was used to estimate the parameters of central tendency and dispersion of arm depth, back width and bust girth. The estimates of the basic parameters are shown in Tables 1 and 2.

Table 1. Basic parameters of the distribution of arm depth in women (cm) by groups and age categories

Group	Age	N [a]	$\bar{x}$ [b]	s [c]	CV [d] (%)	95% CI [e]		Range	
						h_1	h_2	Min.	Max.
I.	-29	205	19,2	2,6	13,4	18,8	19,5	12,0	25,6
	30-39	140	19,3	2,7	13,8	18,8	19,7	11,0	26,0
	40-49	140	20,2	2,4	11,9	19,8	20,6	14,5	26,0
	50-59	97	20,0	2,5	12,5	19,5	20,5	14,0	26,0
	60-69	96	22,0	3,1	13,9	21,4	22,7	15,0	32,0
	70-79	110	20,8	2,7	12,8	20,3	21,3	14,0	28,0
	80-85	107	20,4	2,8	13,9	19,9	21,0	14,0	28,0
	Total	895	20,1	2,8	13,9	19,9	20,3	11,0	32,0
II.	-29	253	19,4	3,1	16,1	19,0	19,8	13,2	30,0
	30-39	175	19,5	3,0	15,5	19,1	20,0	15,2	29,0
	40-49	191	19,8	3,2	16,2	19,3	20,2	13,5	30,0
	50-59	147	20,4	3,4	16,5	19,9	21,0	16,0	33,0
	60-69	109	19,7	2,6	13,4	19,2	20,2	15,9	27,0
	70-79	119	20,0	3,0	15,0	19,5	20,6	14,0	29,0
	80-85	115	20,0	3,4	16,9	19,3	20,6	12,9	29,0

	Total	1109	19,8	3,1	15,8	19,6	20,0	12,9	33,0
III.	-29	168	16,5	2,4	14,4	16,1	16,9	12,0	26,0
	30-39	127	16,7	1,8	11,0	16,4	17,1	11,0	23,3
	40-49	154	17,1	2,4	13,8	16,8	17,5	11,0	26,0
	50-59	110	17,5	2,3	13,2	17,1	17,9	12,0	23,0
	60-69	87	20,0	2,2	11,0	19,6	20,5	14,0	26,0
	70-79	83	19,3	2,6	13,6	18,7	19,9	13,0	24,7
	80-85	70	20,6	2,3	11,1	20,1	21,2	11,0	24,0
	Total	799	17,8	2,7	15,1	17,7	18,0	11,0	26,0

[a] number of cases, [b] arithmetic mean, [c] standard deviation, [d] coefficient of variation, [e] 95% confidence interval

Table 2. Basic parameters of the distribution of women's back width (cm) by groups and age categories

Group	Age	N [a]	$\bar{x}$ [b]	s [c]	CV [d] (%)	95% CI [e]		Range	
						h_1	h_2	Min.	Max.
I.	-29	205	34,3	3,9	11,3	33,8	34,8	26,0	46,0
	30-39	140	36,1	4,3	11,9	35,4	36,8	24,0	47,0
	40-49	140	36,4	4,4	12,0	35,6	37,1	28,0	51,0
	50-59	97	37,7	4,2	11,2	36,8	38,5	30,0	48,0
	60-69	96	37,3	4,8	12,9	36,3	38,3	29,0	50,0
	70-79	110	37,7	4,5	12,0	36,8	38,5	28,0	50,0
	80-	107	37,2	4,5	12,1	36,3	38,0	27,0	50,0
	Total	895	36,4	4,5	12,3	36,1	36,6	24,0	51,0
II.	-29	253	34,2	3,5	10,2	33,8	34,6	24,5	44,0
	30-39	175	35,4	3,4	9,7	34,9	36,0	25,0	44,0
	40-49	191	36,5	3,7	10,2	36,0	37,0	26,0	48,0
	50-59	147	37,3	4,0	10,6	36,7	38,0	27,0	49,0
	60-69	109	37,9	3,4	8,9	37,2	38,5	26,5	47,0
	70-79	119	37,2	4,2	11,2	36,4	38,0	27,5	47,0
	80-	115	36,8	3,9	10,6	36,1	37,5	28,0	47,0
	Total	1109	36,2	3,9	10,8	35,9	36,4	24,5	49,0
III.	-29	168	33,5	3,6	10,7	33,0	34,1	26,0	44,0
	30-39	127	35,9	3,6	10,0	35,3	36,6	27,0	47,0
	40-49	154	36,2	3,5	9,7	35,6	36,8	27,0	44,0
	50-59	110	37,6	3,4	9,1	36,9	38,2	29,0	45,5
	60-69	87	40,6	3,6	9,0	39,8	41,3	32,0	51,0
	70-79	83	39,7	4,7	11,9	38,6	40,7	28,0	51,0
	80-	70	41,1	4,3	10,4	40,1	42,2	29,0	48,0
	Total	799	37,0	4,5	12,2	36,7	37,4	26,0	51,0

[a] number of cases, [b] arithmetic mean, [c] standard deviation, [d] coefficient of variation, [e] 95% confidence interval

Table 3. Basic parameters of bust girth distribution in women (cm) by groups and age categories

Group	Age	N [a]	$\bar{x}$ [b]	s [c]	CV [d] (%)	95% CI [e]		Range	
						h_1	h_2	Min.	Max.
I.	-29	205	90,3	8,1	9,0	89,2	91,4	68,0	125,0
	30-39	140	95,0	10,1	10,6	93,3	96,7	72,0	128,0
	40-49	140	97,8	11,4	11,7	95,9	99,7	72,0	134,0
	50-59	97	104,7	10,5	10,0	102,6	106,8	86,0	133,2
	60-69	96	107,4	13,0	12,1	104,8	110,1	76,0	137,0
	70-79	110	104,7	9,8	9,4	102,9	106,6	78,0	128,0

	80-	107	101,9	11,8	11,6	99,6	104,1	76,0	129,0
	Total	895	98,8	12,0	12,1	98,0	99,6	68,0	137,0
II.	-29	253	91,2	6,2	6,8	90,5	92,0	73,5	111,0
	30-39	175	93,5	6,4	6,8	92,6	94,5	80,0	112,0
	40-49	191	98,1	8,0	8,2	96,9	99,2	80,0	125,0
	50-59	147	102,6	9,3	9,1	101,1	104,2	82,5	134,0
	60-69	109	103,8	8,2	7,9	102,2	105,3	80,4	120,0
	70-79	119	103,3	11,5	11,1	101,2	105,4	66,0	142,0
	80-	115	102,5	10,4	10,1	100,6	104,4	80,0	128,0
	Total	1109	98,0	9,7	9,9	97,4	98,6	66,0	142,0
III.	-29	168	88,5	6,6	7,5	87,4	89,5	78,0	126,5
	30-39	127	94,0	9,2	9,8	92,4	95,7	77,0	128,0
	40-49	154	98,2	9,4	9,6	96,7	99,7	78,0	129,0
	50-59	110	102,0	10,5	10,3	100,0	104,0	70,5	129,0
	60-69	87	105,1	11,4	10,8	102,7	107,5	83,0	131,0
	70-79	83	104,6	11,1	10,6	102,1	107,0	69,0	131,5
	80-	70	107,2	11,6	10,8	104,4	109,9	79,0	127,0
	Total	799	98,2	11,6	11,8	97,4	99,0	69,0	131,5

[a] number of cases, [b] arithmetic mean, [c] standard deviation, [d] coefficient of variation, [e] 95% confidence interval

Table 4 shows the mathematical expressions for calculating the proportional measurements (arm depth and back width) for women's clothing.

Table 4. Proportional measurements and mathematical calculations of parameters for the construction of women's clothing

Proportional body measurements	Mathematical expressions for the calculation of parameters for the construction of women's clothing
Arm depth - Ad (cm)	1/10 Bust girth + 10,5 cm
Back width – Bw (cm)	1/8 Bust girth + 5,5 cm

Table 5. Values of depth of the arm and back width, by groups, obtained through mathematical calculations

Age	Depth of the arm			Back width		
	I. group	II. group	III. group	I. group	II. group	III. group
20-29	19,5	19,6	19,4	16,8	16,9	16,5
30-39	20	19,9	19,9	17,4	17,2	17,3
40-49	20,3	20,3	20,3	17,7	17,8	17,8
50-59	21	20,8	20,7	18,6	18,3	18,3
60-69	21,2	20,9	21	18,9	18,5	18,6
70-79	21	20,8	21	18,6	18,4	18,6
80-85	20,7	20,8	21,2	18,2	18,3	19,9

The parameters (arm depth, Figure 5 and back width, Figure 6), which were determined by mathematical calculations and empirically for each group of respondents observed, are shown graphically below.

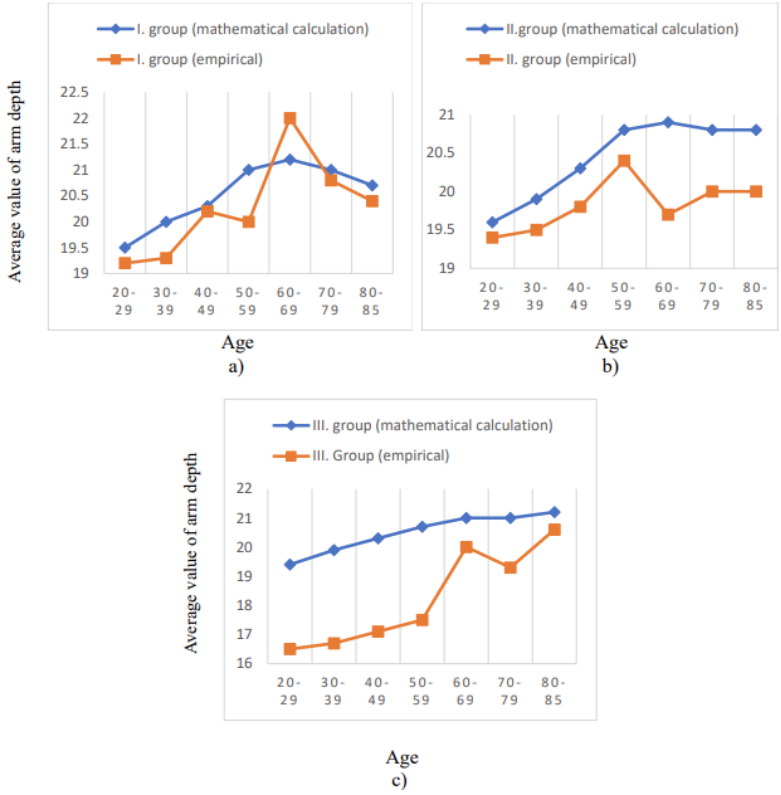

Figure 5. Graphical representation of the arm depth values: a) I, b) II. group and c) III. group

It can be seen from the graphs that the empirical values of arm depth are lower for most respondents compared to the mathematical calculation. The empirical values of the observed measure are most similar to the mathematical calculation in the first group of respondents. Furthermore, in the 60-69 age group, a significant difference in the depth of the arm is observed in the age group of 60-69 years in both the first and second groups of respondents, while in the third group, this difference is most pronounced in the youngest age group, at 2.9 cm.

The graphical representations of the values for back width for all three groups of respondents show smaller deviations in all observed age groups, with the difference in the III being most pronounced in the 60-69 and 70-79 age groups. The difference in the values for back width in the 60-69 age group is 1.7 cm, in the 70-79 age group the difference is 1.4 cm.

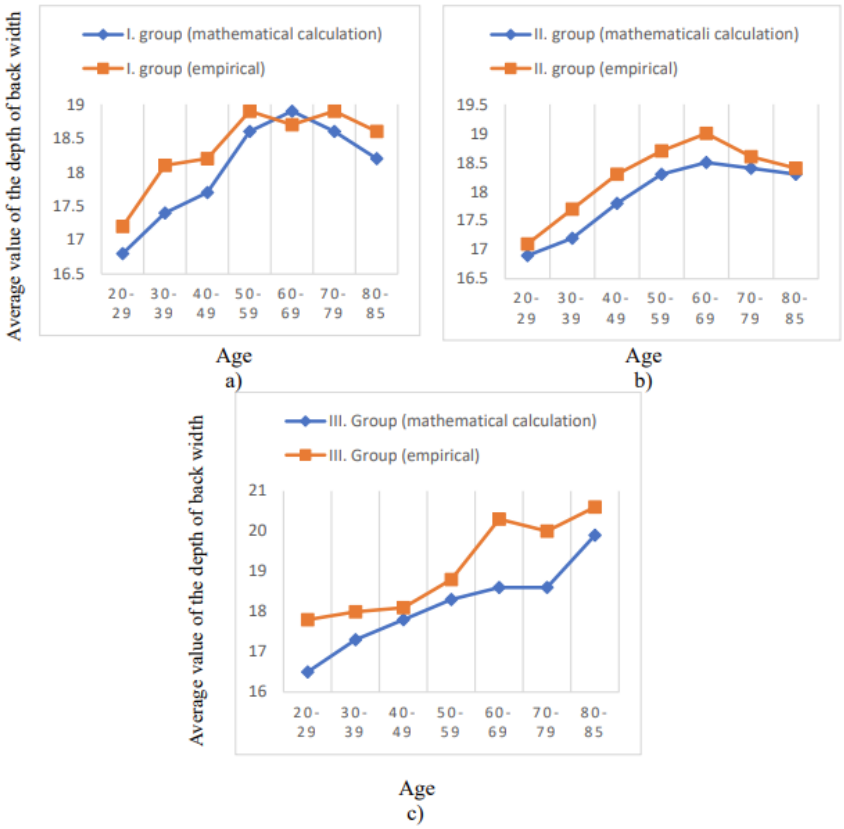

Figure 6. Graphical representation of back width values: a) I. group, b) II. group, and c) III. group

5. Conclusion

Monitoring changes in the dimensions of the human body is extremely important for the industrial production of clothing. In this way, it is possible to correct the cut of the garment when certain body measurements change significantly by tracking them at certain time intervals. Proportion measurements are determined by mathematical calculations based on the ratios of the most important body measurements. The results of the study suggest that the average values of arm depth differ more when comparing the mathematical calculations and the values empirically determined from the back width, which indicates the importance and necessity of carrying out anthropometric examinations. The identified deviations must be incorporated into the basic structure of the garment in order to improve the fit and increase the quality of the garment.

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Inspiration from Slavic mythology in contemporary fashion design

Franka Karin[1], Valentina Pliško[2] and Irena Šabarić Škugor[3]

[1] Department of Textile and Clothing Design, University of Zagreb Faculty of Textile Technology, Zagreb, Croatia
[2] Department of Textile and Clothing Design, University of Zagreb Faculty of Textile Technology, Zagreb, Croatia
[3] Department of Textile and Clothing Design, University of Zagreb Faculty of Textile Technology, Zagreb, Croatia

E-mail: franka.karin@ttf.unizg.hr

Abstract: The work explores the culture, religion and customs of the ancient Slavs with an emphasis on Slavic mythology and key mythological figures - Svarog, Perun and Veles. The term mythology is defined as a set of myths of a particular religion or civilization. The experimental part of the work shows the development of the author's fashion collection from sketch to realisation, which is the result of a diploma thesis by the second author under the supervision of the first and third author of this work. The collection combines tradition with modern design approaches presented in the computer programme Clo3D with the aim of examining and verifying the selected design from the collection in the context of the construction and modelling of cuts and their fit on the wearer's body in order to avoid prototyping in the sense of sustainable development.the purpose of the computer programme Clo3D in this thesis is to test the selected design, cuts and intended materials on customised avatars in order to identify and, if necessary, correct possible defects in the modelled cuts before the actual realisation of the garment.The work offers insight into the creative process of reinterpreting Slavic mythology through contemporary fashion expression.

Key words: Slavic mythology, clothing, fashion collection, Clo3D

1. Introduction

The paper explores the mythology of the ancient Slavs with the aim of creating a fashion collection inspired by their religion and deities. Slavic mythology, religion, and significant deities were analyzed as the main source of inspiration for clothing design. The Slavs are the largest European ethnolinguistic group of Indo-European origin who, during the Great Migration of Peoples, settled the areas of the Adriatic and Aegean Seas, the Balkan Peninsula, and the Eastern Alps. They are divided into South, East and West Slavs. Before adopting Christianity, the Slavs practiced a polytheistic religion, known as

Slavic mythology. Many elements of the old Slavic faith have been preserved through Christian customs and language, which testifies to the existence of Slavic paganism, which significantly influenced their customs and clothing culture. The experimental part of the work shows a fashion collection that contains ten models, the process of construction and modeling of cuts and one realized model.,The result of the fashion collection is the collaboration of the authors of this thesis as part of the research for the final thesis of a fashion design student. The clothing collection, construction and modeling were created in the Clo3d computer program, which also shows a virtual view of the realized model. The purpose of the Clo3D computer programme in this research is to test the selected design, cuts and intended materials on customized avatars in order to identify and, if necessary, correct possible flaws in the modelled cuts before the actual realisation of the garment. The paper aims to bring closer the rich, but insufficiently researched culture of Slavic ancestors and show how it can be creatively interpreted through contemporary fashion design. [1,2].

2. Slavic religion

Due to the lack of reliable written sources, Slavic mythology has not been fully reconstructed, and the existing information is based on chronicles such as Nestor's and Saksa's Grammaticus. Slavic religion was polytheistic, and its existence is confirmed by today's geographical names and folk customs. Many Christian customs and symbols are actually reshaped Slavic rituals and beliefs. Thus, Slavic gods often received Christian parallels, for example, Svantevid as St. Vid, Veles as St. Blaise, and the cult of Perun through St. ElijahIn addition to polytheism, an important role in Slavic religion was played by dualism, or the belief in the conflict between good and evil, which is reflected in deities such as Bijelobog and Crnobog. Some deities were particularly revered, such as Perun, the god of thunder, and Svarog, the god of the sun. They are the main inspiration for the design of the clothing collection of this work [3].

2.1. Slavic deities

The Slavs, despite believing in many deities and mythical beings, worshipped one supreme deity who was superior to all other gods, and was compared to Zeus or Jupiter. He rules over “heavenly things” and does not participate in everyday events. Although the sources are divided, in the Russian tradition Perun is considered the supreme god, while in the Baltic tradition that place is attributed to Svarog, and in some places to Svantevid. In keeping with the dualistic nature of Slavic religion, Bijelobog and Crnobog are personifications of good and evil. Bijelobog, the god of light and day, is associated with positive deities such as Perun, Triglav, Svantevid, and Veles, while Svarog is considered closest to Bijelobog. In contrast, Crnobog is associated with negative deities such as Morana, the goddess of death. Despite this, the Slavs tried to appease Crnobog in order to avoid his malice [3,4].

2.1.2. Slavic god Svarog

Svarog, the god of the sky and the Sun, is the only Slavic deity whose name originates from an ancient Indian myth (Svarog or Varuna). The cult of the Sun god was widespread in many ancient religions, and Svarog is often compared to the Greek Uranus. Although some sources identify him with Perun or even subordinate him to him, the author Spasoje Vasiljev emphasizes that Svarog, as the daily present Sun, has a more significant role than Perun, whose influence, through rain and thunder, occurs only occasionally [3,5].

Figure 1: God Svarog [6].

2.1.3. Slavic god Perun

Perun, the god of thunder, lightning, light, fire and justice, is one of the most important deities of Slavic mythology. His role in the Slavic pantheon is similar to that of Zeus, Jupiter, or Thor in other mythologies. The cult of Perun was widespread, as evidenced by numerous temples, sanctuaries, toponyms, and symbols such as the iris flower. In folklore, he is portrayed as a strong and powerful deity who punishes the breaking of oaths and brings rain, which is why he is associated with names like Daždbog and Strijelbog. During the Christianization, Perun is identified with St. Elijah, which transfers his attributes into the Christian tradition, which Nestor's chronicle confirms [3-5].

Figure 2: Statue of Perun on Učka [7].

2.1.4. Interpretation of Slavic mythology in the Clo3D computer program

Clo3D computer program for construction, modeling and design of clothing is a significant digital tool in the clothing industry that contributes to sustainable development because it enables the preparation of basic and modeled cuts and the virtual realization of the selected designBased on this, it is possible to identify and eliminate irregularities in the cut and fit of the garment on the wearer's body, which eliminates the need for the creation of conventional prototypes. Displaying garments and their properties in virtual space contributes to the maximum possible utilization of fabric, reducing intercutting losses and preserving the environment, which is especially important for the textile industry [8].

3. Experimental part

The inspiration for the fashion collection is the mystical deities Svarog and Perun, as they are among the most important in the Slavic pantheon. The collection combines the spirit of yesteryear with elements of contemporary fashion, with additional inspiration drawn from the works of designers such as Simone Rocha, Rick Owens and Daniel Roseberry. The experimental part of the work involves designing a women's fashion collection of 10 models, showing the entire design process from mood boards and sketches to final realization, Figure 3. Digital tools such as Procreate for illustrations and technical drawings and Clo3D for construction, modeling and tailoring were used. One of the models shows the manufacturing process in detail, including a 3D view and photos of the sewn garment. The collection uses earthy tones and materials that imitate natural fabrics of animal origin, creating an atmosphere of connection with nature and the heritage of Slavic paganism [9].

Figure 3: Moodboard with collection sketches and selected materials and colors for the collection [9].

3.1. Collection description

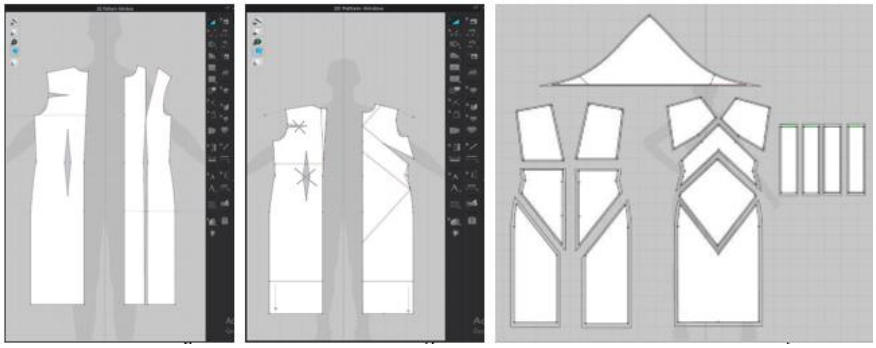
Figure 4 shows the fashion and technical drawings for five of the ten models from the collection that are described below, including the realized model 5.

Model 1: Sleeveless dress with a “V” neckline, ankle length with two pairs of diagonal seams on the front and back and diagonal mesh in the hip area and fashion accessories, hat and gloves from wrist to elbow. Model 2: High-waisted skirt with two diagonal pleats, ankle-length and short top with a raised collar and oversized gloves. Model 3: Short jacket with a high collar and accentuated shoulders and a long mermaid skirt with a high waist and two diagonal buttonholes. Model 4: A dress with an accented top that has two diagonal seams in the hip area, ankle length with long gloves and a headscarf that covers the shoulders. Model 5: Dress "T" dress silhouette, "V" front and back neckline, ankle length with three pairs of diagonal seams on chest, waist and hips, gloves and head cover [9].

Figure 4: View of 5 models from the collection [9].

4. Results

The construction and modeling of the cut of the realized model were made in the Clo3D computer program for clothing size 38. By entering mathematical expressions of basic and construction measurements for the virtual avatar, tailoring parts of the appropriate size were obtained. Figure 5a shows the basic dress cut, Figure 5b shows the modeled cut according to the selected model and design, and Figure 5c shows the cut parts in the Clo3D computer program [9].



a b c

Figure 5: Basic construction, modeling and cutting parts of the realized model in the computer program Clo3D [9].

Figures 6a and 6b show a simulation of the realized model of the front and back parts in the Clo3D computer program on a virtual avatar.

a b

Figure 6: Simulation of the realized model in the computer program Clo3D [9].

Figure 7 shows the front and back of the realized model according to the imagined design inspired by Slavic mythology.

Figure 7: A realized model inspired by Slavic mythology [9].

5. Conclusion

Research has shown that Slavic culture, mythology and customs continue to strongly influence the area of Croatia, but are rarely used as inspiration in fashion design, which further prompted the research of this work to determine whether one specific culture can be applicable in fashion design and whether it is possible to incorporate it into digital tools related to the construction and modeling of clothing in the context of fashion design. The process of creating a collection inspired by Slavic mythology and clothing forms that were present in Slavic civilizations, from inspiration to the creation of the finished model, is based on simple silhouettes, earthy tones and natural materials with faux fur details. This proves that Slavic culture has many elements that are inspiring for fashion design and the creation of fashion collections that are in harmony with nature and the criteria of sustainable development due to their simple forms that do not leave behind much intercut loss. The use of the Clo3D programme enables a realistic simulation of models from the fashion collection on customized avatars and reduces material consumption, as the programme offers the possibility to check modelled cuts and their fit on the wearer's body, eliminating the need to create prototypes and thus achieving a modern and sustainable design approach.

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The influence of digital nomads in a contemporary collection

Irena Škugor, Helga Alaker, Franka Karin and Blaženka Brlobašić Šajatović

University of Zagreb Faculty of Textile Technology, Zagreb, Croatia

E-mail: irena.sabaric@ttf.unizg.hr

Abstract: The paper describes selected groups of traditional and contemporary nomads with a particular focus on digital nomads through the prism of dress and perceptions of identity. The daily clothing routines of traditional nomads and their relationship to clothing are analyzed in comparison to digital nomads. Particular attention is paid to the phenomenon of digital clothing as a means of expressing identity through social networks. In the experimental part of the paper, a collection inspired by the diversity of nomadic communities is presented with the aim of designing sustainable fashion.

Key words: digital nomad, contemporary fashion, digital clothing.

1. Introduction

The world we live in is constantly changing. Digitalisation has given people flexibility in their choice of workplace and place of residence, which is why they are no longer necessarily tied to the place where they work. Before the neo-nomads, there were various nomadic groups, people who lived in tribes, were closely connected to each other and to nature and preserved their culture, tradition and heritage over a long period of time, which was reflected in clothing and textiles. Some groups of traditional nomads still exist today, even if they are not as distinct as in the past.

Traditional and digital nomads are a type of tribal group, although digital nomads do not live in tribal communities like traditional nomads. Both types of nomads wear clothes according to climate, needs and place of work. Digital nomads had a fixed abode at the beginning of their lives, and their decision was to change their lifestyle and relocate. Traditional nomads move all their lives. Digital nomads are not bound by traditions or customs like traditional nomads, unlike tribes, they tend to be loners and choose clothing with different characteristics.

2. **Traditional nomads**

In general, traditional nomads worldwide can be divided into three types: Hunter-gatherers (who move in search of food), pastoral nomads (who move with their livestock) and peripatetic nomads (who move to sell their crafts). [1]

Hunter-gatherer nomads can be considered the oldest form of human community. They include the Tlingit in America, the Khoisan and Bushmen in Africa, the Nukak-Maku in Colombia and the Bushmen. They are characterised by a variety of hunting and gathering strategies depending on the environment, such as hunting animals, catching big game, fishing, gathering insects and wild plants. It is assumed that they have largely died out due to the development of agriculture or have switched to agriculture and animal husbandry.

Pastoral nomads are peoples who herd flocks and travel with them. They move around in search of green pastures, depending on the needs of their animals. They live mainly in Central Asia and West Africa. There are a large number of such nomads in Iran, including the Bakhtiari, Qashqai, and Shahsavan. Peripatetic nomads are known as traders. They can be found all over the world. They travel from place to place to trade. Their livelihood is based on craftsmanship and highly specialised individual skills, which in a way corresponds to the lifestyle of digital nomads. [1]

Beliefs and customs are deeply rooted among traditional nomads. As they have no fixed abode, they define themselves by what they carry with them. Their identity is closely linked to their clothing and dress and was well portrayed in Tony Gatlif's documentary film "Latcho Drom"," which documented the lifestyle of a Roma group from India to Egypt to Europe. The best known example of peripatetic nomads are the Roma, and they live all over the world. In the United States, South America, Europe, Russia, the Middle East, North Africa and North and Central Asia. The Roma migrated to Eastern and Western Europe via Persia in the 13th century, travelling from India, which they had left around 1,000 years ago. Their professions included metalworking, buying and selling horses or cars, fortune-telling (mostly by women), selling handicrafts and playing music. Their clothing is distinctive and clearly reflects their religion, customs and ethics. They have a philosophy of cleanliness. The upper and lower body are washed separately, as the lower body is considered "unclean" and one does not want to "soil" the upper body. The head is particularly protected from impurity. Hats worn by men and scarves worn by married women are to be kept away from all surfaces (such as the seat of a chair) or other clothing that touches the lower body. Women must wear a skirt long enough to cover their legs at least to mid-calf. Depending on the time and place, clothing changes and adapts from tribe to tribe. [2]

In Mongolia, the nomadic way of life is particularly widespread. For centuries, the nomads have lived in yurts, called gerek in Mongolian, which still adorn the country's landscape today. Both sexes wear the so-called deel, which they wrap around their bodies in the form of a cloak, preferably made of colourful silk, and fasten at the waist with a long belt, trousers and occasionally a silk waistcoat. In cold weather, the coat is lined with silk, cotton or fur. Heavy leather boots are worn in all seasons. Mongolian women traditionally wore very elaborate headdresses with silver decorations that identified them with certain tribes and clans. The men also wore hats

as a sign of tribal affiliation. Today, children and young people dress more modernly and traditional nomadic clothing is becoming increasingly rare. In Ulaanbaatar, for example, you can see young people wearing T-shirts with the words "Brooklyn" and "California" on them. [2,3]

In the book Nomads of Niger, Marion Van Offelen and Carol Beckwith analyse the nomads who cross the steppes of central Niger and can be counted among the last nomads of Africa and the world. The authors present the clothing and habits of the members of the clans. During the migration, they go to markets and equip themselves with things that they buy mainly from the Tuareg: leather saddlebags for the men's camels, colourful blankets, colourful woollen yarn to decorate the conical hats, silver pendants, brass rings and hair shells. [4]

Depending on the climate in which they move, there are numerous differences in clothing and customs. Only a few examples of nomadic communities are mentioned in this article, as analysing each one would require a much longer text. In recent times, young people are increasingly rejecting traditions and orientating themselves towards global clothing trends.

3. Nomads in contemporary fashion

Collections inspired by the traditional clothing of various nomadic groups can be seen on the catwalks, as seen at fashion houses such as Chanel, Temperley London, Burberry Prorsum and Saint Laurent. This style is somewhat reminiscent of the hippie subculture of the 1970s.

The nomadic style also suggests an 'off the grid' lifestyle centred on contemporary ideas of sustainability, reuse and recycling." [5]

Nowadays, punks, beatniks, skinheads and mods can also be categorised as belonging to the 'tribal' fashion. Although there was no movement or nomadism in the literal sense, international relations helped spread these styles around the world. With the development of technology, lifestyles changed, but certain clothing styles of subcultures spread more easily around the world. In this way, they not only spread their movement, but also their way of dressing without having to physically move.

4. Digital nomads

One of the increasingly popular and widespread lifestyles is digital nomadism. Modern technology and new types of workplaces allow people to work from home, which means they can change their place of work according to their personal skills and preferences. They are not tied to a single location. This has also led to a new lifestyle where work can be done in a "home office", i.e. without a physically defined static workplace such as an office or institution.

Digital nomadism is about people, usually entrepreneurs and freelancers, travelling the world "nomadically" and doing their work using the digital tools at their disposal. Digital nomads are strongly driven by the desire to escape confinement and often seek out tropical, oriental, cheap, lifestyle-orientated or "Instagram-friendly" places where they can meet "interesting" people and "like-minded" people". [6]

In 1899, the American sociologist Thorstein Veblen emphasised the social role of clothing in his study “Theory of the Leisure Class”. He pointed out that in modern

society, the function of expressing wealth is performed by excessive purchases and the accumulation of goods. It is a kind of monetary competition in which fashion is a typical form of extravagance, especially in clothing, but also in other areas.

For digital nomads, the basis of respect does not revolve around the accumulation of goods or the possession of wealth, as in the money culture described by Veblen. Most of them do not see themselves as high-status travellers.

They gain their prestige through social media, which they use as a means of communicating with the world to show how unique their lives are. They show off their “wealth” in the form of beautiful pictures and online diaries. Compared to the fact that, according to Veblen’s theory, people flaunted their status through fashion and clothing, one could say that this new idea of a leisure class is more sustainable. They do not tend to accumulate objects or clothes, and such an attitude towards things can be seen as more sustainable. On the other hand, with the advent of postmodernism, people's self-image has emerged primarily through clothing. The American anthropologist Ted Polhemus raised the issue of tribal dress with the advent of postmodernism. In analogy to the tribal peoples, subcultures that emerged in the second half of the 20th century as a popular "fashion form", the so-called anti-fashion, demonstrated their affiliation to their group in a spectacular way. You could tell who belonged to the punks, beats, mods, rockers and the like from their clothing and style, just as you could tell which nomadic people they were from the various embroideries, jewellery worn, etc. Tribal peoples dressed quite complexly. It cannot be denied that clothing has always been closely linked to the expression of identity. The shift from fashion to style can be linked to the shift from modernity to postmodernity, so that belonging to a group became more "fashionable" than following a particular clothing trend. The emergence of styles has allowed people to dress according to their own feelings, in accordance with their identity. The digital nomads have also evolved into a kind of "tribe", but their cohesion takes place in online spaces in front of the world." [7-9]

5. Vanchar collection

The clothing collection shown in the work is inspired by traditional and digital nomadism and is called Vanchar. Moving from place to place, only a few things in a suitcase, sustainability, which is so important in today's fast fashion era - all this is combined and shown in the clothing collection.The dominant colour is white. In the collection, it stands for purity, a white horse running free and linen as a natural and comfortable material that flows even at high temperatures. The colour white can stand for a new beginning, like a tabula rasa. Some of the materials that make up the collection have been collected over the years during moves from city to city and from country to country. Items of clothing and everyday objects from second-hand shops, old beads from childhood, remnants of old photo negatives and the like were used.

The collection is designed in such a way that the items can be combined with each other. This means you can put together more outfits with fewer items and support sustainability.

Figure 1. Draped piece of fabric in various combinations, fashion drawings Vanchar collection[10]

Figure 2. Fashion drawings from the Vanchar collection [10]

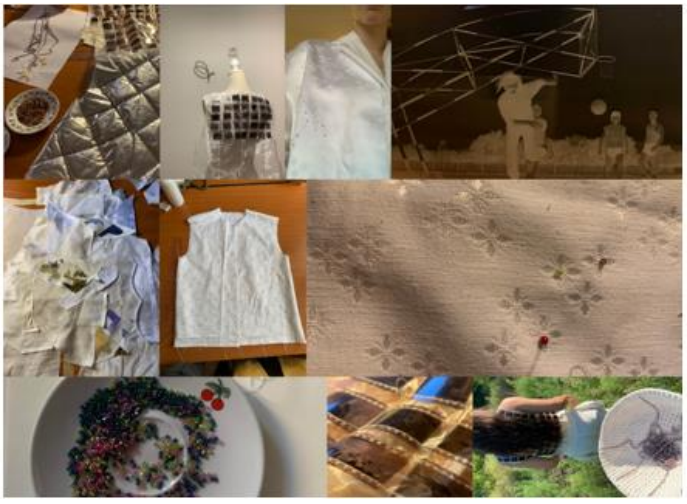

Figure 3. Preparing for the collection

Figure 3 shows a collage of the elements used for the collection and some of the production steps.

6. Results

The photos show the models in the Vanchar collection and some of the suggested combinations. A draped dress becomes a skirt or blouse, white trousers can be the start of a styling for any combination shown in the photos. Negative pieces carry with them memories that are hard to part with, and they don't fit in a travelling suitcase.

Figure 4 shows the outfits of white linen trousers and a top with a light cape made of transparent curtain. Image 5 shows the combination of a draped garment that can be converted into a skirt, blouse or dress. Other garments can also be combined in different ways. Figure 6. shows a combination of white trousers and a jacket with a newly designed waistcoat/poncho that can be worn on both sides. One side is decorated with beads, the other is a silver piece of fabric reminiscent of thermal blankets designed to keep a person warm. A dome-shaped headdress decorated with beads can be seen hanging around the head.

Figure 4. Vanchar collection outfits 1[10]

Figure 5: Vanchar collection outfits 2[10]

Figure 6. Vanchar collection outfits 3 [10]

7. Conclusion

Nomads undergo various transformations and change like the times and circumstances in which they live. This collection is inspired by the constant changes in the dwelling places of modern nomads, whom we call digital nomads. Nevertheless, the influence of tradition in the collection can also be seen in the reuse of materials, embellishments, beads and headpieces to give the garment a personal touch.

The colour white represents new beginnings and the hope of digital nomads who move from place to place, constantly searching for their place in the sun of life. The cuts have been refined so that the garments can be combined in as many ways as possible. Either some garments can be transformed into several of them, or they can be combined with each other. This leaves room for personal interpretation by the person who will be wearing them. This way you take fewer things with you in your suitcase and travel less burdened with material things.

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Sustainable Textiles from Agricultural Waste and Their Role in the European and Serbian Fashion Industry

Danka Djurdjic[1], Dusan Trajkovic[2], Marija Pesic[1], Ineta Nemeša[1] and Valentina Bozoki[1]

[1] Technical Faculty „Mihajlo Pupin" Zrenjanin, University of Novi Sad, Serbia
[2] Faculty of Technology Leskovac, University of Nis, Serbia

E-mail: danka.djurdjic@tfzr.rs

Abstract: The fashion industry is one of the most polluting global sectors, due to its intensive consumption of natural resources and the generation of significant amounts of waste. In response to growing environmental challenges, increasing attention is being directed toward sustainable textile materials derived from agricultural waste. This paper explores the potential of next-generation bio-sustainable materials such as Piñatex, Bananatex, Orange Fiber, coconut and rice husk fibers, all of them from parts of plants typically discarded as agricultural waste (e.g., stems, peels, and leaves). Through an analysis of their production processes, technical properties, and commercial applications, the paper highlights their ecological and economic advantages. Special attention is given to Bananatex, an innovative material made from the stems of the abacá banana plant, used in a wide range of functional and design-forward products. The paper also discusses the presence of sustainable materials in Europe and Serbia, supported by data on textile waste and consumer awareness—especially among young people. It can be observed that interest in sustainability among youth is increasing, but also reveal significant barriers, such as lack of knowledge, the prevalence of greenwashing, and limited availability of sustainable products. It can be concluded that agricultural waste holds great potential for transforming the fashion industry, provided that technological, informational, and market strategies are developed in parallel to support this transition.

1. Introduction

The fashion industry, as one of the most dynamic yet highly polluting global sectors, stands at the center of a growing debate on sustainability and responsible resource management. Textile production—especially at an industrial scale—entails massive consumption of water, energy, and pesticides, along with the emission of harmful gases and the generation of substantial waste, from the manufacturing process to the end of a product's life cycle. In this context, a transition toward production models that align with the principles of the circular economy and responsible consumption is essential.

One increasingly prominent and environmentally friendly solution is the use of agricultural waste as a raw material for textile production. This approach involves utilizing parts of plants traditionally considered as waste (such as stalks, peels, leaves, and harvest residues) and processing them into biodegradable, sustainable next-generation materials. These materials not only reduce the need to exploit conventional resources (such as cotton or synthetic fibers), but also help address the issue of agricultural waste management [1, 2].

The advancement of bioengineering technologies has enabled the development of textile fibers from orange peels, pineapple leaves, banana stalks, coconut husks, and even rice and sunflower husks. These innovations are transforming traditional approaches to fashion design and manufacturing, paving the way for an industry that is not only aesthetically relevant but also socially and environmentally responsible [2].

This paper analyzes the status of sustainable materials in Europe and Serbia, as well as the most significant examples of sustainable textiles derived from agricultural waste, with a focus on their production processes, technical properties, and potential integration into the fashion industry. The aim of the paper is to provide a comprehensive overview of the role of agricultural waste-based textiles in the sustainable transformation of the fashion industry, with particular emphasis on the European and Serbian contexts, and to highlight the importance of education, innovation, and systemic solutions in this field.

2. Global fiber market

According to a report published by Textile Exchange (2023), a global non-profit organization founded in 2002 and dedicated to transforming the fashion, textile, and apparel industry toward more sustainable practices, global fiber production reached a record high of 124 million tons in 2023, up from 116 million tons in 2022. Since 2000, when production stood at 58 million tons, global fiber output has more than doubled. If current trends continue without significant changes, production is projected to reach 160 million tons by 2030, as illustrated in the graph in Figure 1.

According to these findings, polyester remains by far the most dominant fiber, accounting for more than half of total production since 2000, with a clear upward trend. Man-made cellulosic fibers (MMCFs), such as viscose, modal, and lyocell, show moderate growth. Cotton (represented in green) maintains a relatively stable share, but without significant increase. Plant-based fibers—other (light brown), which include innovative fibers derived from agricultural waste (e.g., Piñatex, Bananatex), currently represent a very small share but have growth potential. In contrast, wool, silk, and other animal-based fibers are stagnating, with a slight decline in their relative share.

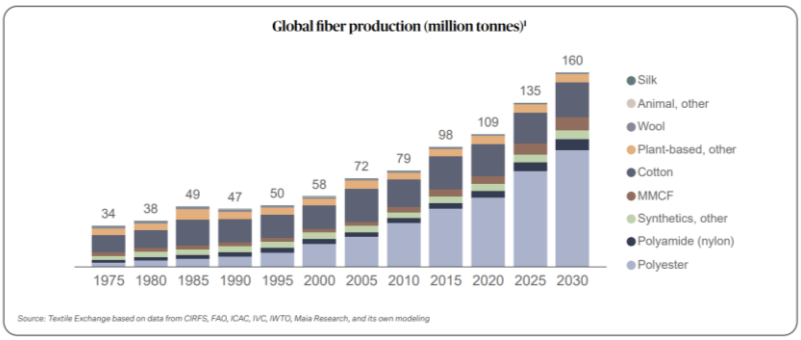

Figure 1. The Growth of Global Fiber Production (2000–2030) [3]

2.1 Other plant-based fibers - Global overview

In addition to cotton, there is a wide variety of other plant-based fibers, such as jute, coir, flax, hemp, sisal, abaca, kapok, ramie, and agave [3]. It is estimated that more than eight million households around the world are involved in their production. As shown in Figure 2, these non-cotton plant-based fibers reached a total global production volume of approximately 6.7 million tonnes in 2023, accounting for around 5% of total global fiber production. Furthermore, as shown in Figure 3, the global production of plant-based fibers has remained relatively stable from 2019 to 2023, fluctuating between 6.3 and 6.8 million tonnes annually, indicating a consistent demand and role in the global textile market.

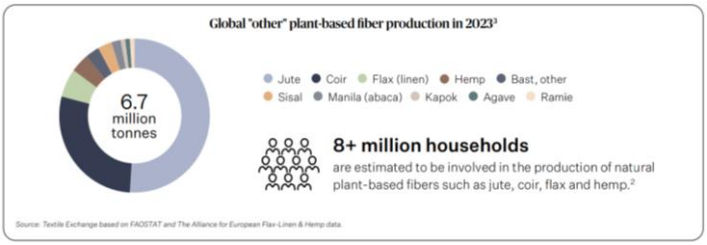

Figure 2. Global Production of Other Plant-Based Fibers in 2023 [3]

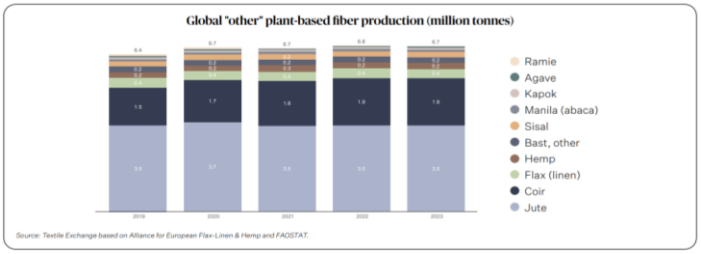

Figure 3. The global production of plant-based fibers from 2019 to 2023 (million tons) [3]

3. Representation of sustainable materials in Europe and Serbia

The study conducted by Schiarolli and colleagues provides a systematic review of 217 scientific papers that analyze consumer behavior toward sustainable fashion across all stages of consumption – from purchasing and usage to disposal. The research emphasizes that most previous studies have primarily focused on younger consumers and women, as they have shown the highest levels of interest and willingness to adopt sustainable behavior patterns. However, the study highlights that while environmental awareness is present, it is not the strongest factor influencing purchasing behavior. Instead, consumers more often make decisions based on aesthetics, comfort, fashion compatibility, and product price. Environmental values become relevant only among consumers who are already strongly committed to sustainability.

In addition, one of the key findings is that a lack of knowledge, skepticism toward sustainability claims, and limited availability of sustainable products in retail outlets represent the main barriers to the wider adoption of sustainable textiles. Particularly concerning is the finding that young people are often exposed to superficial information through social media, which leads to confusion and a reduced ability to distinguish truly sustainable products from greenwashing practices. Interestingly, the study identifies the important role of digital communities, influencers, and online communication in raising awareness about sustainable fashion. Positive examples in celebrity campaigns and the growing engagement of young people in online communities that promote sustainable values significantly influence their willingness to purchase environmentally friendly products [4].

Table 1. Factors influencing sustainable consumer behaviour in the fashion industry

Category	Factors / Examples
Demographic factors	Young women show the highest willingness to adopt sustainable fashion; older consumers generally less engaged
Psychological factors	Environmental awareness, ethical values, personal responsibility
Motivational drivers	Desire for a healthy lifestyle, identity expression through sustainability, achieving social status through “green” consumption
Functional factors	Aesthetic appeal, comfort, durability, multifunctionality
Economic and price factors	Higher cost of sustainable products as a barrier; lack of financial incentives or subsidies
Awareness and knowledge	Limited knowledge of sustainable materials; heavy reliance on social media rather than expert or verified sources

Change facilitators	Skepticism about sustainability claims (greenwashing), limited product availability, habitual impulse buying
Contextual factors	Availability of sustainable options in retail channels, policy support, EU regulations (e.g., mandatory textile waste separation by 2025)

[a] Based on research Schiarolli et al. (2023) [4]

In the last decade, sustainable materials derived from agricultural waste have become a key component in the transformation of the textile industry in Europe. According to the 2021 Textile Exchange report, as much as 56% of the materials used by analyzed global fashion brands were classified as "preferred materials," including natural fibers from renewable sources, recycled fabrics, and textiles made from waste [5]. In this context, Europe leads with 69% of materials having a reduced environmental impact, thanks to stringent EU regulations, an increasing number of circular economy initiatives, and growing consumer demand for ethically produced clothing [6].

A significant indicator of consumer awareness regarding sustainability in fashion is the research conducted in 2023 in France, Germany, Italy, and the United Kingdom. The results showed that, on average, 46.5% of respondents had purchased at least one piece of sustainable clothing in 2022, with Italy recording up to 8% higher than the European average [7]. These data reflect the growing awareness and willingness of citizens to actively participate in sustainable consumption.

The situation in Serbia is significantly more challenging. Although there are no comprehensive statistics on the share of sustainable materials in the domestic fashion industry, it is known that over 9,000 tons of textile waste are generated annually, accounting for 2–4% of the total municipal waste. Recycling in Serbia is almost symbolic [8]. The implementation of a system for the separate collection of textile waste is planned only for the year 2029, which is considerably behind the European deadlines, where this obligation is set for as early as 2025.

Table 2. Comparative analysis of the state of textile sustainability: European Union and Serbia

Element	EU	Serbia
Share of recycled textiles	20-30%	<1%
Share of bio-fibers	3-5%	<1%
Textile waste legislation	Yes	No
Availability of Pinatex / Bananatex	Yes	Limited

In Serbia, there are no official statistical studies on the presence of bio-fibers or bio-based materials in the clothing industry. Based on market review, insights into local

fashion initiatives, and available project documentation, it is estimated that bio-fibers make up less than 1% of the total use of textile materials. The presence of these fibers is limited to:

- academic and research projects,
- small and sustainable brands with local production,
- individual initiatives within circular and sustainable fashion.

In contrast to the European Union, Serbia does not have a specific law that exclusively addresses textile waste. Instead, this area is covered under the general Law on Waste Management. This law includes a classification of textile waste aligned with the European catalog and outlines obligations for producers. However, there are no concrete guidelines for the textile industry. In practice, the recycling of textile waste generated during production is minimal due to a lack of specialized facilities or the existence of large-capacity plants that cannot accommodate the needs of individual textile companies. Additionally, there is a lack of facilities to handle post-consumer textile waste. This highlights the need for more precise regulation and better infrastructure in line with the principles of a circular economy.

4. Awareness of young people about sustainable materials

Regarding the awareness of young people in Serbia on sustainability issues, available research shows a high level of interest and support. According to data from a study conducted by the OIE Serbia organization (2024), as much as 90% of young people support the transition to renewable energy sources, and more than half of them express concern about climate change. However, despite the high level of support for "green" initiatives, only 22% of young people obtain information from verified portals and expert sources, while the majority use social media as their primary source of information, which can lead to a superficial understanding of complex topics such as sustainable fashion [9].

Additionally, a study published in the journal *Sustainability* highlights that "green consumer values" are a key factor in shaping the behavior of young people when it comes to responsible clothing consumption. The authors conclude that young people in Serbia show the potential to become the main drivers of change towards a more sustainable fashion system, provided they are given adequate education and access to information [10].

5. Bio-Fibers from Agricultural Waste: Innovation and Potential for Industrial Application

Bio-fibers derived from agricultural waste can be divided into traditional ones, which have been in use for a long time, and innovative ones, developed as a response to the negative environmental impact of the textile industry. Traditional fibers such as hemp, flax, jute, ramie, sisal, and kenaf have been used in the textile industry for centuries, both for clothing and technical purposes. Recently, their application has gained

renewed value within the framework of sustainable production in the textile and clothing industry.

In contrast to traditional bio-fibers, innovative fibers from agricultural waste are emerging, offering reduced environmental impact from the fashion industry. The production of these fibers reduces the need for renewable resource use and minimizes agro-industrial waste. The most common innovative fibers of this type include those made from pineapple leaves (e.g., Piñatex), abaca stems (Bananatex), orange peels (Orange Fiber), soy, corn, rice, and coffee. These are used to produce regenerated cellulose fibers or non-woven materials. Although still a minority on the market, these fibers show great potential for commercial application in both fashion and technical industries, as they combine environmental sustainability, functionality, and innovative design.

5.1 Piñatex

Piñatex is an innovative material made from pineapple leaf fibers, which are considered a byproduct of agricultural production. Pineapple, one of the most popular fruits in the world, generates a large amount of waste in the form of its leaves, which are usually discarded or burned. However, this waste can be effectively used in the production of Piñatex, thereby creating a sustainable material utilized in the textile industry [11]. Piñatex quickly gained popularity in the fashion industry, recognized as an eco-friendly alternative to products like leather. Its ability to mimic leather while being lighter and more flexible has made it ideal for producing bags, footwear, accessories, and even clothing. Brands such as H&M, Stella McCartney, Hugo Boss, Nike, and Adidas have already incorporated Piñatex into their products, using it for bags, shoes, and sports accessories.

In addition to being environmentally friendly, Piñatex easily integrates into fashion designs due to its exceptional flexibility, durability, and availability in various colors and textures [12]. Piñatex is also used in the production of luxury fashion collections, where its sustainability is further emphasized as an advantage over traditional leather. Interestingly, this material is also being used for car interiors and furniture, expanding its application beyond conventional fashion products [11], [13].

Figure 4. From leaf fibers to finished textile material [14].

5.2 Orange Fiber

Orange Fiber is an innovative plant-based textile material produced from cellulose extracted from orange peels—waste generated by the food industry, particularly during industrial juice production.

Instead of discarding this raw material or using it for low-value purposes, the company Orange Fiber has developed a process that transforms this biological waste into high-quality fibers suitable for the textile industry [15]. The special value of this process lies in the fact that it uses raw material that is otherwise completely unused in the textile industry [15], [16].

Its use in the fashion industry began in 2017, when Salvatore Ferragamo launched the first clothing collection made from Orange Fiber material [17]. Since then, this textile has become part of collections by other sustainable and luxury brands, including Stella McCartney, as a fabric suitable for dresses, blouses, scarves, and eveningwear. Its resemblance to silk, combined with functional properties such as natural antibacterial protection and breathability, makes it appealing to designers seeking to merge aesthetics with sustainability [18].

Figure 5. From fruit peel to finished textile [19,20].

5.3 Coconut Fiber

Coconut Fiber, also known as **coir**, is a natural textile material derived from the outer husk (mesocarp) of the coconut — a waste product generated during coconut processing in the food and cosmetics industries. These fibers have been used for centuries in traditional production of carpets and mats, but today, within the framework of modern sustainable practices, they are increasingly being explored and applied in the textile and fashion industries [21].

The production process involves extracting coarse yet durable fibers from the coconut husk, which is first soaked in water to soften it. After fermentation and drying, the fibers are mechanically separated, sorted, and further processed — most commonly blended with other fibers (e.g., organic cotton or natural latex) to enhance their flexibility and comfort [22], [23].

Although the use of coir in the fashion industry is still in the development phase, coconut fibers are increasingly being applied in the production of footwear, bags, fashion accessories, as well as eco-sports collections. Their resilience, durability, and natural antibacterial properties make them suitable for products that require high endurance and hygiene maintenance [23].

Figure 6. From coconut husk to finished product [24].

5.4. Bananatex

Bananatex is an environmentally sustainable material made from the fibers of the abacá banana plant stems—a tropical plant known for its exceptional strength and durability. The abacá banana, or *Musa textilis*, grows in tropical regions, and its stems—previously considered agricultural waste—are now used to produce high-quality textile material. Bananatex has gained recognition as a sustainable alternative to synthetic fabrics, and its eco-friendly properties and durable design have made it popular among brands focused on sustainable fashion [25].

Use in the fashion industry – Bananatex has become especially popular in the outdoor and fashion industries due to its natural water resistance and high durability. The first brand to incorporate Bananatex into its products was **QWSTION,** which recognized the potential of this material for manufacturing bags and backpacks. The brand became a pioneer in commercializing Bananatex by using it in their eco-conscious collections [26]. Bananatex is naturally water-resistant, providing excellent moisture protection—an essential feature for outdoor products such as backpacks and bags. Additionally, the material dries quickly, making it ideal for items used in demanding weather conditions [25], [27].

Environmental benefits – One of Bananatex's greatest advantages is its contribution to the circular economy. The abacá banana stems, typically discarded as agricultural waste, are repurposed as raw material for fabric production. Using agricultural waste in textile manufacturing helps reduce the amount of waste that would otherwise end up in landfills or be incinerated, thus lessening the environmental impact [28].

Since the abacá banana plant grows quickly and can be harvested every six months, this fiber is a renewable resource that can be sustainably used in textile production. Bananatex is also biodegradable, meaning that—unlike synthetic

materials—it won't leave a long-lasting negative impact on the environment once discarded. This characteristic makes Bananatex an excellent choice for brands and consumers aiming to reduce their footprint on the planet [28], [29].

Figure 7. Life cycle of Bananatex® material [30]

6. Conclusion

Given the depletion of resources and the ongoing global environmental crisis, sustainable textile materials represent a necessary solution. The use of bio-based fibers derived from agricultural waste offers one of the most effective ways to reduce the negative impact of textile production. This approach enables the creation of functional, aesthetically appealing, and design-relevant materials with minimal consumption of new resources. Innovative materials such as Piñatex, Bananatex, Orange Fiber, and coconut fiber are already present on the market and are finding their place in collections by brands that promote circular design and social responsibility.

An analysis of the market and legislative frameworks reveals significant differences between the European Union and Serbia. In the EU, between 20–30% of textile waste is recycled, supported by clearly defined strategies for sustainable textiles (e.g., the EU Strategy for Sustainable and Circular Textiles) and incentives for the use of bio-fibers, which currently represent 3–5% of the market, with a growing trend. In contrast, Serbia recycles less than 1% of its textile waste, and bio-fibers are present only in negligible amounts, mainly through academic and experimental projects. There is no specific law addressing textile waste, which further hampers the development of circular practices.

Achieving real change requires the synergy of multiple stakeholders — policymakers, manufacturers, designers, educational institutions, and end users. Only through a combination of regulatory measures, market incentives, and education can bio-based materials from agricultural waste gain the rightful place they deserve in a modern, sustainable, and responsible fashion industry — both in Europe and in Serbia.

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The impact of new technologies on the textile industry

Ammar Selmanović

University of Bihać, Faculty of Technical Engineering, Bosnia and Herzegovina.

E-mail: ammar.selmanovic@unbi.ba

Abstract: This paper analyzes the impact of new technologies on the textile industry, focusing on the development of smart materials, nanotechnologies, automation and digitalization that transform manufacturing processes and the design of textile products. New technologies enable the creation of materials that respond to external stimuli, such as fabrics that change color, stiffness, or generate energy, as well as textiles capable of detecting chemicals and gases. The integration of electronics into textile products, such as clothing and interior materials with embedded microcomputers, creates new opportunities for networking the textile industry with other sectors, such as electronics. Smart polymers, characterized by high electrical conductivity, energy storage and transformation capabilities, and chemical responsiveness, represent key research areas in the textile industry. The development of fabrics that regulate temperature and humidity in interiors and offer additional functionalities, such as integrated lighting, is also expected. In textile production, digitalization and automation enable more precise and efficient processes, reducing material and energy consumption. The application of 3D technologies allows detailed visualization of garments, improving design and quality control. The implementation of new technologies in the textile industry contributes to the improvement of manufacturing processes, increased efficiency, and competitiveness of companies. These innovations allow for greater precision, resource savings, and the development of new products, enabling the textile industry to address contemporary market and sustainability challenges.

1. Introduction

The concept of "new technologies" encompasses a wide range of definitions across various fields influenced by technological advancement and innovation. While the term is commonly used to describe technological innovations, it can also refer to the continuous evolution of existing technologies. Its meaning often varies depending on the context in which it is applied, such as industry, media, commerce, science, environmental protection, or education. Generally, the term "new technologies" refers to technologies that are currently in development or undergoing transformation. It

frequently includes areas such as information technology, biotechnology, nanotechnology, automation, and other fields that introduce novel ways of solving problems or enhancing existing technological processes. Through innovation in production processes, new technologies contribute to the creation of a new value framework for production and development, shaping modern approaches to meeting both existing and emerging human needs. At the same time, they drive changes in the relationship between humans and work, as well as in the forms and structures of social organization. [1]

Accordingly, it may be concluded that new technologies constitute a fundamental driver of economic growth and a catalyst for the creation of new employment opportunities—both at the level of individual business entities and within society at large. In the development of new technologies, the efficiency of production resources emerges as a critical determinant, wherein capital may, but does not necessarily, assume a position of primary importance .[2]

2. Smart Materials and New technology in Textiles

The term *smart textiles* originates from the concept of intelligent materials, first defined in Japan in 1989. The earliest example of a smart textile was silk thread with shape memory properties. Smart textiles refer to textile materials and structures that can sense environmental stimuli, react to them, and adapt accordingly by incorporating functional components into the fabric itself.

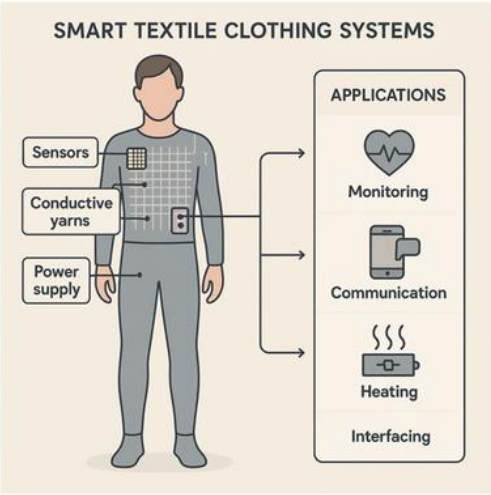

Figure 1. Functional structure and applications of smart textile systems in clothing. [3]

These stimuli and responses may be electrical, thermal, chemical, magnetic, or mechanical. Unlike high tech fabrics with passive features such as breathability or fire resistance smart textiles actively respond to their surroundings.

Smart clothing, a key application of smart textiles, can detect signals, process information, and generate appropriate responses. Terms like interactive clothing, intelligent apparel, and smart garments are often used interchangeably.

These systems typically integrate sensors, actuators, and electronic devices, enabling the fabric to change shape, stiffness, color, temperature, or electromagnetic properties. Examples include color changing fabrics, garments made from conductive polymers that emit light, and textiles that regulate temperature for improved comfort. [4]

Much of recent innovation has been driven by the advancement of smart materials and responsive structures that interact with external environmental conditions. These include textiles capable of changing color or stiffness in response to specific stimuli. Other cutting-edge innovations involve the application of nanotechnology to manipulate material properties at the molecular level, enabling functionalities such as chemical and gas detection, kinetic energy generation, and integration of flexible sensor systems. Parallel to these advancements, fabrics are being developed that can transmit data and energy.

Contemporary innovation is evident in applications such as textile-based walls and ceilings with unique properties, fabrics embedded with lighting systems, and distinctive furniture designs. Equally important is the expanding use of these materials in both outdoor environments and interior spaces. These fabrics, known for their high durability, are manufactured similarly to traditional interior textiles but undergo advanced finishing processes to enhance softness, resistance to fading, moisture, and stains, as well as ease of maintenance.

Looking ahead, it is highly likely that microcomputers will be embedded in virtually every fabric whether used in garments or interiors facilitating deeper integration between the textile and electronics industries. Smart polymers, in particular, are attracting growing research interest due to their exceptional properties, including mechanical strength, electrical conductivity, energy storage capabilities, and the ability to convert energy into light or mechanical motion, as well as their sensitivity to chemical stimuli.

In the future, it is expected that curtains, upholstery, and wall coverings will autonomously regulate ambient temperature and humidity, with integrated lighting components enhancing both functionality and user experience. [5]

2.1 Nanotechnology in textile industry

Nanotechnology is transforming the textile industry by enhancing the functionality of fabrics at the molecular level. It enables the development of textiles that are water-repellent, wrinkle-resistant, antimicrobial, antistatic, UV-protective, and conductive.

These advanced properties are achieved without compromising the softness, breathability, or comfort of the fabric. Commonly used nanomaterials include silver (Ag), titanium dioxide (TiO_2), zinc oxide (ZnO), silica (SiO_2), and carbon nanotubes (CNTs). These materials are either embedded in fibers or applied as surface coatings.

Cotton, polyester, silk, and synthetic fibers are the primary textile substrates used in nanotechnology applications. For instance, Ag nanoparticles provide antibacterial properties, while TiO_2 and ZnO offer UV protection and photocatalytic self-cleaning effects. SiO_2 particles enhance hydrophobicity, mimicking the lotus leaf structure. CNTs significantly improve tensile strength and conductivity, enabling the production of smart textiles.

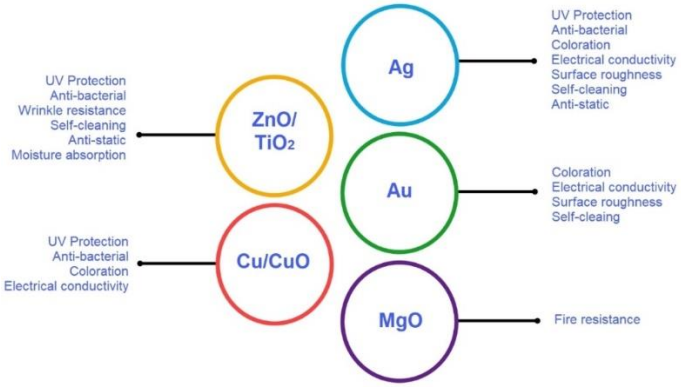

Figure 2. Nanoparticles that are used to impart functional properties on textile. [6]

Electrical conductivity in fabrics is achieved using conductive polymers such as polyaniline (PANI) and polypyrrole (PPy), often in combination with nanoparticles. These textiles can function as sensors, actuators, or energy storage devices, making them ideal for medical, military, and sports applications. Nanogenerators and textile-based supercapacitors can harvest and store energy from motion, light, or friction. Energy-generating fibers can be woven into garments to power LEDs or sensors.

Durability is a key benefit of nanotechnology, as functional effects can remain after multiple wash cycles. Additionally, nanomaterials help reduce the use of chemical finishes, supporting sustainable textile production. Risk assessments of nanotoxicity and environmental release are important considerations in product development. Life cycle analyses are used to evaluate the environmental impact of nano-enhanced textiles.

Overall, nanotechnology enables the creation of multifunctional, responsive, and high-performance fabrics. It bridges fashion and science by introducing smart features into everyday garments. The integration of nanoscale innovations continues to push the boundaries of what textiles can do. [7]

3. Digitalization and 3D Technology in Apparel Manufacturing

The digitalization and integration of 3D technology into the textile and apparel industry has revolutionized the way garments are designed, visualized, and produced. Through advanced 3D software solutions, designers can digitally create, modify, and simulate

garments in real time, accurately visualizing fabric drape and garment fit on virtual avatars. This eliminates the need for multiple physical prototypes, significantly reducing both development time and material waste.

Moreover, the use of body scanning technologies enables precise measurement acquisition, facilitating personalized garment construction and improving overall fit accuracy. This not only enhances customer satisfaction but also reduces return rates in the retail sector. The digital workflow streamlines decision-making processes, allows for rapid iterations in design, and accelerates product development cycles.

Figure 3. 3D garment simulation interface showing virtual clothing on a digital avatar. The system enables designers to visualize fabric behavior, adjust garment fit, and make real-time design modifications without physical samples, thereby enhancing efficiency and sustainability in apparel development.

In addition to improving efficiency and sustainability, 3D technology supports mass customization and empowers manufacturers to respond quickly to dynamic market demands. It represents a critical component of the broader digital transformation of the apparel industry, aligning with modern industry principles and supporting smarter, more sustainable production systems. [8]

Furthermore**,** in contemporary apparel manufacturing processes, machines with manual or semi-automatic lubrication systems are now rarely used. This shift highlights the impact of advanced technologies across all stages of garment production, where fully automated lubrication systems have become standard. With the advancement of new technologies, the first commercially available sewing machines that require no lubrication have emerged.

These innovations stem from the development of miniature sewing machines designed for integration with robotic arms. Such machines enable sewing in any spatial orientation and contain no oil within their housings. Instead, they utilize bearings made

from specialized self-lubricating materials, such as polytetrafluoroethylene (PTFE or Teflon). [9]

Figure 4. Self-lubricating PTFE strip with steel backing. [10]

In addition to sewing machines equipped with automatic lubrication systems, a crucial aspect of modernizing garment production is the adoption of digitalization and advanced technologies. High-performance computers integrated into sewing equipment allow for faster and more precise stitching processes. This technological progress leads to significant savings in both materials and thread consumption.

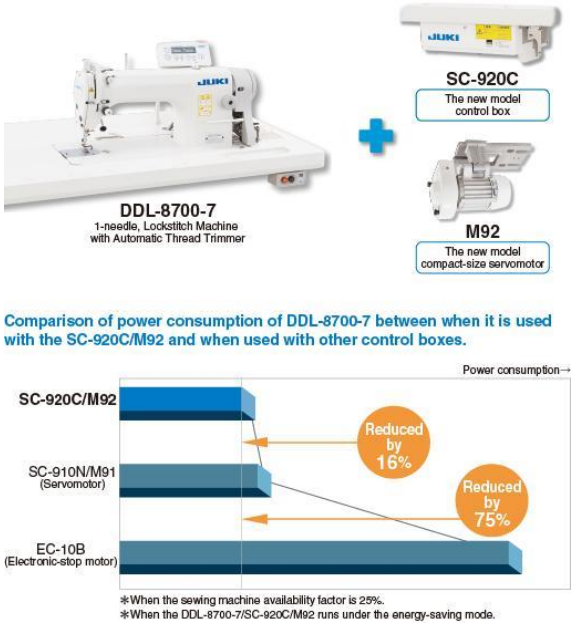

Figure 5. Sewing machines motor comparison. [12]

Moreover, the motors used in newer sewing machines contribute substantially to energy efficiency. These modern motors consume considerably less electricity compared to traditional ones, which helps reduce operational costs. They also operate with much lower noise levels, improving the working environment for operators. [11]

Thanks to these innovations, energy savings of up to 70% are achievable in sewing workshops. The combination of digital control and energy-saving motors enhances both productivity and product quality. Consequently, manufacturers can maintain competitive pricing even amid rising energy costs. Such improvements are essential to sustain the garment industry in the face of ongoing economic and environmental challenges.

Implementing these technologies not only supports energy conservation goals but also increases overall factory efficiency. As a result, the transition toward smarter and greener production systems becomes a priority. Seamlessly integrating these advanced components is relatively straightforward and cost-effective. Therefore, garment producers are encouraged to invest in such upgrades to future-proof their operations. [13]

4. Impact of new technologies on the textile industry

The introduction of Industry 4.0 technologies is significantly reshaping the textile industry by enabling smarter, more efficient, and sustainable production processes. Key technologies such as the Internet of Things (IoT), robotics, 3D printing, and smart sensors are enhancing operational performance, improving product quality, and reducing production time and costs. These advancements facilitate real-time tracking, seamless communication, and personalized customer experiences, which collectively contribute to greater supply chain transparency and responsiveness.

One of the most notable benefits of Industry 4.0 is the optimization of factory operations, including improved health and safety conditions, predictive maintenance, and inventory management. Automation of repetitive and physically demanding tasks allows workers to focus on higher-level, more intellectually stimulating activities, potentially increasing job satisfaction and productivity. Moreover, the rising demand for higher-quality products is driving production expansion, which can generate new job opportunities that require advanced technical skills.

However, the adoption of Industry 4.0 is not without challenges. High costs of technology implementation and limited digital readiness among employees are significant barriers for many textile companies. The increased automation also raises concerns about job displacement, especially for low-skilled workers, as machines and robots increasingly perform tasks traditionally done by humans. While some experts foresee a reduction in certain job roles, others argue that new, more skilled positions will emerge, necessitating comprehensive retraining and upskilling initiatives.

Employee perspectives highlight a moderate level of awareness and preparedness for Industry 4.0 changes, accompanied by a desire for additional education and mentoring to ease the transition. Essential skills for the future workforce include digital literacy, programming, problem-solving, and effective decision-making. Addressing workplace environmental conditions, such as temperature and ventilation, remains an important factor in ensuring employee well-being alongside technological progress.

Therefore, Industry 4.0 technologies present both significant opportunities and challenges for the textile sector. Their successful integration depends on balancing technological innovation with human-centered strategies that prioritize workforce development and sustainability. By investing in employee training and fostering adaptability, the textile industry can harness the full potential of new technologies while maintaining a competitive edge and supporting a resilient labor market. [14]

5. Conclusion

New technologies are a key driver of transformation in the textile industry, bringing significant changes to production processes, efficiency, and sustainability. Smart materials and nanotechnology enable the development of functional and adaptive fabrics that actively respond to environmental stimuli, while digitalization and 3D technologies revolutionize garment design and manufacturing, reducing development time and material waste.

The introduction of automation, advanced sewing machines with automatic lubrication, and energy-efficient motors contributes to increased productivity and cost reduction, while improving working conditions. Industry 4.0 technologies such as IoT and robotics further enhance production monitoring and control but also pose challenges related to workforce digital readiness and potential job displacement.

Successful integration of these technologies requires balancing innovation with a strong focus on human resources through education, retraining, and improved working environments. This approach will help the textile industry maintain competitiveness, sustainability, and adaptability in a rapidly evolving technological landscape.

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Development of a collection of women's skirts with a focus on environmental

Blaženka Brlobašić Šajatović, Laura Vragović, Ksenija Doležal and Irena Šabarić Škugor

Faculty of Textile Technology University of Zagreb, Zagreb, Croatia

E-mail: blazenka.brlobasic@ttf.unizg.hr

Abstract: The textile sector is one of the biggest polluters of the environment. With the rise of fast fashion, the amount of clothing produced and worn is increasing and various solutions are being sought to solve this problem. The article describes the work of designer Vivienne Westwood, whose collections will be the inspiration for the development of her own collection of women's skirts. The experimental part shows the design, construction and modeling of skirts. Recycled material was used to create one of the skirt models.

1. Introduction

Vivienne Isabel Westwood was one of the most influential British fashion designers and a pioneer of punk and new wave fashion. Born on 8 April 1941, Westwood became famous in the 1970s when, together with Malcolm McLaren, she opened the "SEX" boutique in London, which became the centre of the punk movement.

Her designs are characterised by a combination of traditional British cuts with rebellious, provocative elements – such as safety pins, chains and tartan patterns. She often used symbols of the subculture and expressed political messages about the environment, consumer society and the fight against injustice through fashion.

Westwood has redefined her collections several times throughout her career – from the punk phase to historically inspired collections and elegant haute couture models. She has received numerous honours, including the title of Dame of the British Empire.

She is not only remembered as a designer, but also as an activist for climate change and human rights. Her style and design inspiration became the inspiration for the development of her own collection, in which she emphasised recycling [1].

2. Vivienne Isabel Westwood fashion collections

The following chapters will present the work of the aforementioned designer, through various fashion styles.

2.1 Punk fashion

The co-owners of a boutique at 430 King's Road, London, together with her husband, have shaped the punk aesthetic by designing T-shirts with eye-catching red Nazi swastikas, Figure 1, bondage trousers and jackets, jumpers pierced with safety pins, cotton waistcoats with zips that expose nipples, and more [1].

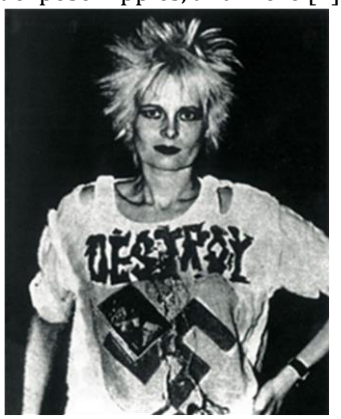

Figure 1. Vivienne Westwood with her T-shirt design [3]

2.2 Sex Pistols and SEX boutique

Westwood designed clothes for her and McLaren before opening their first shop, Let It Rock, in 1971, which catered to the "Teddy Boy" subculture that was experiencing a style revival in the 1950s. in 1972, they renamed the shop Too Fast to Live, Too Young to Die and changed their focus to the emerging rocker/biker style influenced by Marlon Brando, a popular American actor at the time. in 1947 they changed the name of the shop again to SEKSm figure 2. and sold clothing inspired by S&M (sado-masochistic), then they met the Sex Pistols and added their punk line. SEX was at the centre of the fashion scene and Westwood and McLaren played a key role in defining and marketing the punk look just as it was taking over the streets of London.

Their first show together was in 1981, when McLaren was fascinated by the 1980s film The Island and Westwood focused on 18th century dandies and Native Americans. The film was inspired by the nineteenth century and Native Americans. All these influences were brought together in a new look and in the "Pirates" collection they presented at the show, which returned to the catwalks after 40 years and inspired other designers [2].

Figure 2. "Pirate" collection, 1987. [4]

2.3 Political activism and environmental awareness

Vivienne Westwood is celebrated as one of the world's most influential fashion designers and activists. Her brand has always been about more than just making clothes and accessories. This gift of creation has allowed her to voice her opinion on the state of the world, which is still not fair for all and whether it will ever be fair for all, Figure 3.

She has used her collections and fashion shows as a platform for positive activism while spending many years speaking tirelessly about the effects of climate change.

Figure 3. London Fashion Week Spring/Summer 2013. [5]

2.4 Influence on Haute Couture

The designer decided to rename her shop "World's end" and was actually sad about the fate of the punk style. But that didn't stop her from presenting herself on the fashion scene again. In the same year, she designed a collection inspired by Philip K. Dick's novel Blade Runner and presented her line "Punkature", figure 4.

Slika 4. Punkature“collection 1982., Fashion Week [6]

A few collections later, in spring/summer 1990, the "Portrait" collection was released. The collection was filled with dozens of corsets inspired by rococo painters such as François Boucher. This idea made the collection controversial once again. The Rococo era symbolised eroticism, and in conjunction with the corsets in this collection, Westwood's motifs were called into question. A great advocate of this collection, Valerie Steel, explains the motifs of the corsets that resonate with the collection: "Long denigrated as a symbol of female oppression, the corset began to be re-understood as a symbol of female sexual empowerment." In this way, Westwood emphasised gender and was very progressive when it came to gender exploration. She stood in the balance between masculinity and femininity. In this particular outburst, women became what they had never been, and she emphasised this by discovering the history of art, but also playing with its threads in a way that turned history on its head, Figure 5 [2]. The retail industry currently is dominated by fast-fashion and just-in-time production seeking to increase fashion trends. Yet, due to the economic crisis worldwide, disposable incomes are on the wane and clothes at disposable prices are losing their appeal. There is a growth of a new movement counteracting the demand for fast fashion—the “Slow Fashion” movement [7].

Figure 5. „Portrait“ spring/summer collection 1990. [8]

3. Experimental part

In exploring the style and general fashion of Vivienne Westwood, elements that appeared in her creations were used in the creation of her own collection, such as belts, recycled denim, t-shirts, etc. She was a designer who in a way started the punk culture in the fashion world, pushing back the influence of fast fashion and making many designers realise that we can do great things ourselves if we understand the influence of ourselves as individuals, and only then how we can preserve and influence everything around us and what we should care about, the balance of nature and ethnicity. This was the starting point for the collection, which is inspired by punk fashion. In the realisation of the model, the emphasis was placed on materials that were not purchased but used from already manufactured clothing. This work shows a model that was realised, Figures 6 -9. [2]. Modeling was carried out in such a way that it adapted to the greatest possible use of materials, yet kept the form and satisfied the criteria of aesthetics and functionality.

Figure 6. Part of the women's skirt collection a) model 1, b) model 2, c) model 2

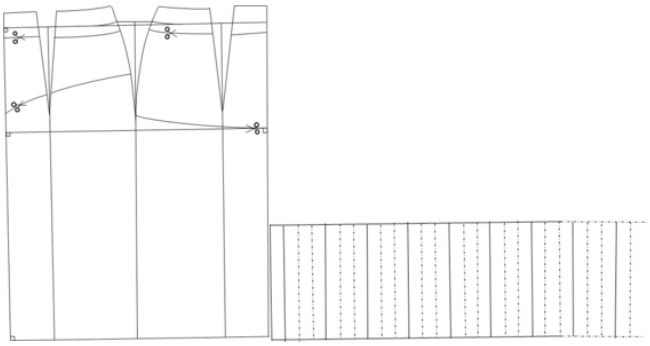

Figure 7. Modeling a skirt model 1

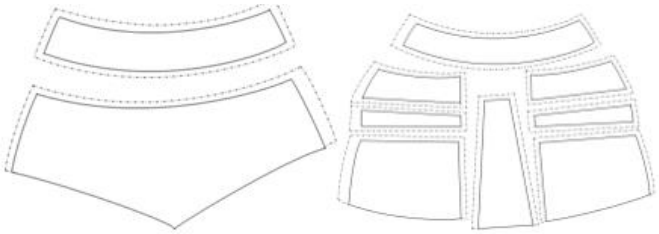

Figure 8. Tailored parts with added seam allowances

Figure 9. Realized model 1 [2]

4. Conclusion

Vivienne Westwood has left an indelible mark on the fashion world with her unique approach to design and the fashion industry. Over the course of her career, which spanned several decades, Westwood not only redefined the aesthetics of fashion, but also exerted a strong influence on social norms and cultural values. Her ability to combine classic elements with avant-garde styles enabled the creation of new fashion trends that often defied convention. In addition to her contributions to fashion, Vivienne is known for her activism and advocacy for environmental awareness, making her a role model not only in the fashion industry but also in society in general. The piece is part of a collection of women's skirts that highlight the famous designer's style with a focus on environmental awareness. The development of our own skirt collection, inspired by the design elements of the researched designer and her work, also contributes to ecological sensitivity in terms of utilizing wearable clothing. There is room for the development of the collection and other clothing items in the direction of recycling materials, following the same style in design. The construction of the clothing is not demanding, and the modeling is performed in a way that utilizes the maximum possible amount of material

for the new clothing item. This method of modeling, which adapts to the above parameters, contributes to sustainability.

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Ebru technique in the context of textile design: combination of traditional art and digital 3D technology

Amela Mlivić and Dejla Ramić

University of Bihać, Faculty of Technical Engineering, Bosnia and Herzegovina

E-mail: amela.mlivic@unbi.ba

Abstract: Mass production of textiles and clothing has led to greater consideration of sustainable alternatives when it is about textile and fashion design. As one of the answers to all the harmful effects of industrialization and automation, there are traditional craft practices, their encouragement and increasing application. Traditional forms of production, including textile and clothing dyeing, are closer to human in their essence, because they are based on sustainable practices that respect sociological and cultural aspects, advocating the concept of slow fashion. In this context, this paper investigates the application of the traditional Ebru dyeing technique, the possibility of its application in textile design, through a combination of traditional design and visual reinterpretation using contemporary 3D digital tools. Relying on historical references, the paper deals with traditional aspects and the significance of the Ebru technique, exploring its historical path, all the way from the Far East through Anatolia to the Western countries, following the Silk Road. As a unique dyeing technique, it has seen its application in various forms in many cultures. From the painting of official documents against forgery, all the way to the decorative painting of books, Ebru has also found its place as an artistic expression in textile design. This research paper presents a synergy between traditional artistic expression and the application of contemporary technologies, with an emphasis on the preservation of traditional textile design techniques through their transformation into a contemporary context.

1. Introduction

Craft techniques and traditional practices in the development of textiles and clothing are often mentioned in the context of sustainability and slow fashion. They refer to traditional craft techniques such as knitting, embroidery, but they are also related to certain phases in textile and fashion design such as spinning, weaving, hand dyeing, making textile prints, manipulation of the textile surface, pattern making or the finishing process. Essentially, this model advocates quality that is embodied in the production process itself, using fine natural materials, and the result is a unique textile

or fashion design that meets all parameters of sustainability and slow fashion [1]. Traditional techniques in textile and fashion design are increasingly experiencing their interpretation through contemporary artistic expression. It seems that the increased value of the product can be achieved through its symbolism and the possibility of connecting with people. The touch of the human hand and the sense of tradition contributes to a completely different observation of clothing compared to the prevailing fashion system. Historically speaking, beginning of clothing making and textile dyeing is linked to craftsmanship and handwork.

Today, many techniques of making and dyeing textiles are often applied through the concept of slow fashion, thus reviving the forgotten ancient methods of dyeing textiles, which are deeply rooted in the ancient past of human existence. In this context, through further research, this paper will deal with the ancient method of dyeing, better known as Ebru. Due to its historical importance, its application is present in many cultures of ancient countries. As an alternative method, respecting the concept of slow fashion, it can be implemented through the development of textile design when it comes to the sustainable and contemporary development of textile print. In addition, the work shows the possibility of integrating traditional artistic practice such as Ebru together with contemporary digital software for design, which result is a modern and relevant way of presentation in order to preserve traditional artistic values and their reinterpretation.

2. Ebru-historical overview and cultural significance

Since there are many theories about the origin of Ebru art, the exact origin of this technique is not known. The assumptions of many scientists state that the Ebru origin is related to the historical region of Turkestan in Central Asia [2]. Theories about the origin of this technique are related to the Silk Road thanks to the connection between Central Asia and China at that time, where this technique developed alongside the development of paper production. In the 17th century, the Turks developed this art of paper painting, where it experienced its complete form and has remained until today. The original purpose of this technique was to protect official documents against forgery [3], thanks to the variety of designs that can be achieved with this technique and the near-impossibility of making exactly two identical copies of the Ebru pattern. In addition, this technique was used to decorate the pages of books as a decorative technique, and over time it began to be applied through textiles.

During the 18th and 19th centuries, the art of Ebru spread to other countries, through Turkey and France, all the way to the Mediterranean countries, Spain and Italy. European countries took over the principles of the Ebru art and adapted it to their own recipes and indigenous materials. In this way, Ebru patterns were developed with beautiful motifs of flowers, figures and animals, which originally originated in Turkey. In addition to the traditional Ebru technique, characteristic European examples of this

art were also developed, such as Antique, Dutch, French and Spanish. Each country associated with this art, viewed through its historical context, contributed to the development of beautiful patterns of this art that we know today [4]. Through the historical prism, the Ebru technique is also significantly related to the traditional Japanese paper dyeing technique Suminagashi, the technique of applying ink pigment over the surface of water onto paper. This technique also represents one of the historical techniques of paper coloring through hand-decorating paper, making manuscripts and printed works [3], the interpretation of which can still be seen today.

Historically, every interpretation of this art arose from the functional need to decorate paper and calligraphy, it was defined as a craft and viewed from that perception, and over time it became associated with art and surpassed the craft aspect. Over time, Ebru became a cultural symbol thanks to the political influence on the promotion of cultural and commercial importance in the territory of Turkey, and its interpretation through works of art and the textile industry [3]. Precisely for this reason, the importance of this traditional technique is confirmed by its place on the list of intangible heritage of UNESCO in 2014, which reached a turning point in raising awareness of the preservation and application of this art [2].

3. Characteristics of the Ebru technique and methods

There are several interpretations of the Ebru technique that are based on basic and simple principles. These methods differ according to the type of medium used, different types of materials, inks, colors and patterns based on, which a different result is achieved. Basically, each method involves creating a gelatinous mass with water that prevents the paint from penetrating to the bottom. The paint remains on the surface of the water where with the help of combs and other suitable tools, a characteristic Ebru pattern is carefully created and transferred to paper or fabric. The simplest materials for Ebru technique are non-toxic and sustainable, such as a medium of carrageenan and water, surfactants for diluting the paint, aluminum sulfate for preparing fabrics and the like [3]. The Ebru technique has not changed throughout history, the basic process is always the same and requires control of the paint on the surface to achieve the desired design of the pattern.

It is important to mention some of the methods and main media in order to achieve the best result. For example, the Japanese Suminagashi marbling method is a technique that requires the least possible control of the process, unlike the Western versions of this technique where precision is required when creating patterns. The method achieves the greatest fluidity of the paint and tends to naturally float the colors [4]. On the other hand, the oil method is a rougher technique because it is more difficult to achieve control and the desired appearance. This method achieves the free-form design, texture and shape characteristic only of this technique. Oil paints are previously diluted with turpentine or alcohol, which ensures that the paint remains on the surface and

floats [3-4]. The method using tempera and gouache achieves a solid and precise appearance of lines thanks to the density of the substrate, but requires adaptation to external influences such as temperature, humidity and dust.

The basic method of performing Ebru art involves the use of ox bile, characteristic of traditional Ebru, which in combination with paint, enables a method of creating a pattern in a way that breaks the surface tension and allows the paint to float on the surface. What is important with this method is density regulation. With an insufficient amount of ox bile, the dye will not be distributed properly, while on the other hand, a larger amount leads to deformation of the pattern, where the dye loses density.

In order to keep the color on the paper or fabric, it is necessary to apply alum, which is powdered in the form of aluminum sulfate, which ensures a better chemical bond during dyeing. The method using carrageenan medium is the closest to the traditional Ebru technique. Carrageenan or Irish moss is a powder extracted from dried seaweed found along the coast of Ireland. In combination with water, it thickens the mass and it is the best medium for floating colors on the surface of the water and enabling their manipulation [2]. This method was used in the experimental part of the research to create samples of the textile design collection.

4. Experimental approach

4.1 Creating textile design collection

In this experimental process, the basic principles were used, which are closest to the traditional Ebru technique. Natural cotton fabric and media that are non-toxic and not harmful to the environment were used, which is one of the most significant advantages of this type of artistic textile dyeing, unlike industrial textile dyeing. First of all, it was necessary to provide a working space so that the process could proceed smoothly and neatly. Climatic factors in the working space play an important role, because the ideal temperature in this case is 18^0C and the amount of air humidity should be high in order to minimize the amount of dust. In general, the Ebru pattern is best displayed using natural fabrics such as cotton and silk, where it is possible to dye only pieces of textile or the entire garment. In this case, experimental pieces of 100% natural cotton, cut to a format of 20x30cm were used. Fabrics with a softer texture that include cotton fiber absorb the dye best and keep it on the surface, while on the other hand, fabrics with a pronounced surface texture like velvet are less suitable for Ebru. The fabric must be pre-treated with alum, which the fibers must absorb in order for the fabric to retain its color. In general, Ebru works on both natural and synthetic fibers. Another important element for performing the experiment is additional equipment such as combs, toothpicks or droppers used to manipulate the paint on the surface. By applying different equipment and methods, different patterns are achieved on the surface. The paint must spread over the surface of the water, without penetrating to the bottom. In this case, before the final works, samples of smaller textile format were tested in a shallow container with a small

amount of the required medium (water, carrageenan and ox bile combined with dyes). In order for the material and color to work well in this process, it is best to make several test samples of the textile.

In addition to preparing the conditions of the working space and equipment, providing natural fabric, it is also necessary to provide a frame in accordance with the format of the fabric. The framework serves to prepare a gelatinous mass that is achieved with distilled water and media such as carrageenan or tragacanth. With its composition, carrageenan ensures the best results as a thickener in this process, which in normal climatic conditions lasts from 30 to 40 days. On the other hand, tragacanth prevents the deterioration of the color by ensuring the consistency of water, which maintains the vitality of the color and its fixation on the paper. After we provided all the necessary material and equipment, the final samples of the textile collection with characteristic Ebru pattern were made.

This sustainable method of dyeing textiles through its process can enable further use of textile pieces through fashion design, ambient or functional textiles. It can be applied in several ways, and the coloring process itself is simple and sustainable, considering that all the necessary media and colors do not contain toxic chemical substances. Paint pigments are dripped onto the previously prepared surface of the substrate using appropriate equipment, depending on the pattern we want to achieve.

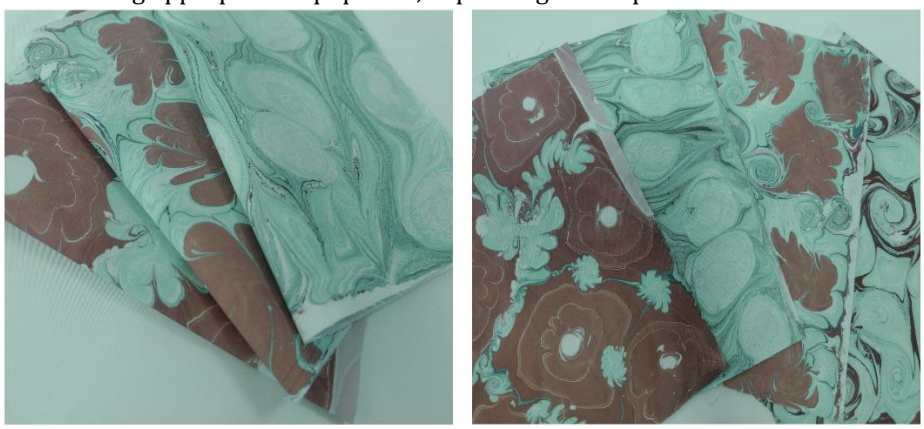

Figure 1. Textile design collection samples with characteristic Ebru motifs.

It is best to use lighter color palettes in the beginning, as the gelatinous mass becomes cloudy and messy over time. The design on the surface of the water can be manipulated until the desired design is achieved. The technique requires precise and soft movements, any sudden movement can disrupt the pattern. After forming the pattern, a piece of fabric is laid on the surface where the fabric dye will be fixed. The piece of fabric should be taken by two corners as straight and precise as possible. After the dyeing process, the fabric should be left to dry naturally, and once dry, the fabric can be washed to remove unnecessary dye [4].

4.2 3D visualization and simulation

In the second part of the experimental approach, the next step was a 3D simulation one of the samples. Thanks to the development of digital technologies and their application in the development of textile and fashion collections, recently there has been an increasing use of 3D virtual simulation systems that enable virtual 3D fashion.

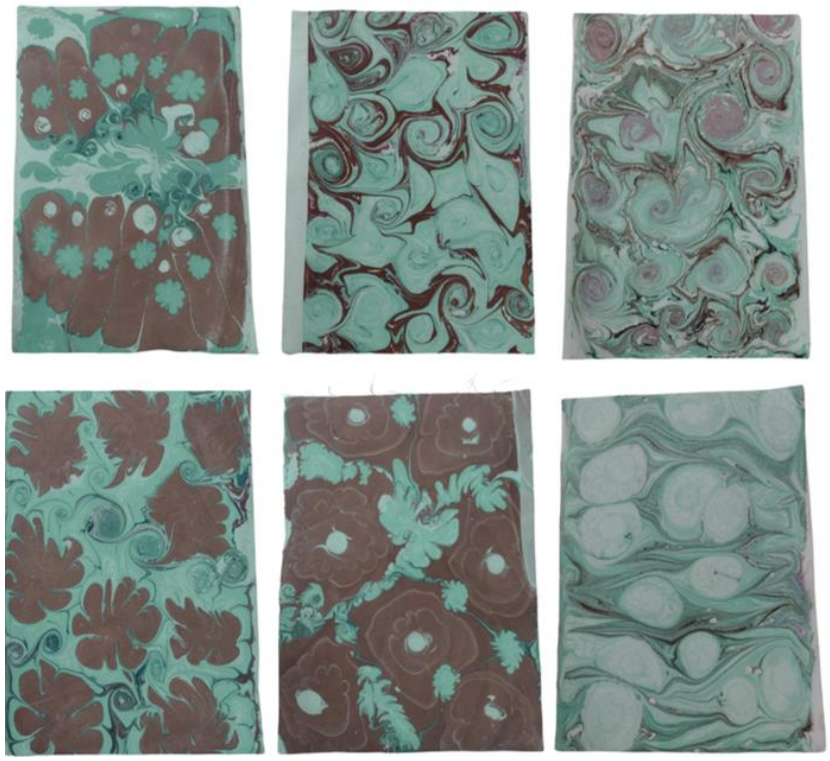

Figure 2. Textile design collection overview.

The integration of design and 3D digital systems enables aesthetic expression and design experimentation in virtual environments that simulate physical space. In dynamic virtual environments, an aesthetic and expressive design simulation effect is achieved, including the criteria of expressiveness, loadability, process sustainability and interactivity. 3D simulation and visualization redefines and shapes completely new experiences related to the development of textile and fashion design [5]. 3D digitization implies CAD modeling, simulation rendering and dynamic simulation in space. It can also be applied through the digitization of the fabric sample design, which was used for the purposes of the experimental part of this work. Digitizing a fabric sample involves a set of information about physical fabric and converting it into digital formats in a virtual environment. Through scanning technology and collecting information through photography, fabric simulation includes its visual characteristics such as color, texture,

shine, structure or surface texture. In addition to the aesthetic characteristics of the fabric, textile simulation also enables experimentation with physical properties such as drape, elasticity, compression and dynamic properties. Fabric pattern simulation implies significant integration with body animation in a virtual environment to achieve a complete virtual design simulation [6].

After creating the textile design collection, the goal was to virtually simulate one of the textile samples on an avatar in a virtual environment, thus achieving a realistic representation of the fabric and its possibility of application in real and physical space.

Figure 3. 3D digital simulation of textile design collection sample in softver CLO 3D.

5. Conclusion

Oversaturation in the current prevailing fashion system has led to an increasing demand for authentic and unique designs with which the customer can connect more deeply. This is exactly the feeling that the long-forgotten ancient techniques of dyeing and making textiles and clothing bring with, carrying a touch of nostalgia for past times, and they experience their form through contemporary artistic expression. Authenticity and unique design are only one of the parameters of the concept of slow fashion, bringing with it innovations through the interweaving of tradition and modern spirit. The oversaturation and availability of fashion trends has led to an increasing demand for something that represents a symbol, a real feeling and emotion through contact with timeless design. In a time dominated by the development of technology and mass production, more and more aware consumers appreciate the traditional techniques of dyeing textiles and making clothes as a means of preserving culture and traditional

values. In addition to being characterized by craftsmanship, the Ebru technique, through its application in textile design, represents a symbolic relationship between culture, tradition, producers and conscious consumers through the articulation of self-identity. Accordingly, digitalization and the possibility of virtual presentation of the application of traditional artistic practices such as Ebru contributes to the preservation of traditional values in accordance with modern presentation possibilities. By developing a methodology for combining these two approaches through traditional and modern digital expression in textile and clothing design, a combination of classic traditional approaches with a modern interactive way of presenting textile design is achieved.

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SECTION/SEKCIJA
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Public relations management in the modern business environment

Ljiljana Stošić Mihajlović[1] and Marija Mihajlović[2]

[1] Academy of Applied Technical and Preschool Studies, Niš, Serbia,
[2] Ministry of Construction, Transport and Infrastructure, Belgrade, Serbia

E-mail: ljiljana.stosic.mihajlovic@akademijanis.edu.rs

Abstract. Public relations management (PR) represents a key function in the modern business environment, enabling organizations to build and maintain a positive reputation, communicate with target groups and respond to market challenges. PR is a vital function in business that helps organizations connect with their audiences and manage their image effectively. This paper explores the importance of PR, key strategies and challenges facing organizations in a dynamic business environment. The paper emphasizes the role of PR in creating trust between the organization and its interest groups, as well as the ability to inform the public about the organization's products, services and values. Key PR management strategies include analyzing the situation, defining goals, creating clear messages, choosing communication channels, and tracking results. Also, the challenges faced by PR experts are discussed, such as technological changes, crisis situations and public expectations for transparency and social responsibility. Special attention is paid to the management of crisis situations, where the importance of a proactive approach and effective communication during a crisis is emphasized. In conclusion, the paper points out that successful public relations management requires continuous adjustment of strategies in accordance with changes in technology and consumer needs, thus ensuring the long-term success of the organization.

Keywords: marketing, public relations, modern business environment, strategies

1. Introduction

Public relations (PR) is a key aspect of any modern business environment. In the era of digitization and fast communication, PR is developing and adapting to new trends and market needs. This paper analyzes the importance of public relations management, their strategies and the challenges they face in modern business. PR includes a series of activities that are not only related to communication with the media, but also to the creation of mutual understanding and support between the organization and its public. The goal of PR is to influence the attitudes and behavior of target groups through

planned and strategic communication processes (Pilar, 2024). In the modern context, PR is often associated with digital platforms and social networks, where communication takes place faster and more directly than ever before.

The abbreviation PR can also refer to the profession of individuals who deal with public relations management, and who are responsible for building the image of a company or brand (Selaković, 2018). PR is defined as "the management of communication between an organization and its public" (Grunig & Hunt, 2019). Contemporary business conditions, characterized by globalization, digitalization and growing consumer expectations, require a strategic approach to public relations.

2. Definition and importance of public relations

Public relations is the process of establishing and maintaining mutual understanding between an organization and its public. In a rapidly changing world, where information is available faster than ever, organizations must actively manage their image and reputation. Jast publicity is defined as the publication of information about the company and its products and services in public media that are not financed by the company (Stošić Mihajlović, 2022).

PR is defined as "a management function that builds relationships between organizations and their publics" (Meiden, 2021). Contemporary business conditions, characterized by globalization, digitalization and growing consumer expectations, require a strategic approach to public relations. According to Edward Bernays, PR is "a key instrument of adaptation, interpretation and integration between individuals, groups and society" (Bernays, 2021). Other authors PR is defined as "a planned and ongoing effort to establish and maintain a good reputation and mutual understanding between the organization and its target public" (Filipović, 2003; Lukić, 2020).

In the modern context, public relations enable organizations to communicate with their interest groups, manage image and reputation, and respond to challenges in the environment. Namely, modern business is characterized by dynamic changes, growing competition and increasing consumer expectations. In such an environment, public relations play a key role in creating trust between the organization and its interest groups. PR enables organizations to:

- Inform the public about their products, services and values.
- Create a positive image through transparent communication.
- They react to crisis situations and manage reputation (Lukić & Bujković, 2020; Lamza-Maronić & Glavaš, 2008).

According to the Institute of Public Relations of Great Britain, PR can change public opinion, create attitudes where there were none, or strengthen existing attitudes (Filipović, 2003). In modern business, PR plays a key role in shaping the public's perception of the organization. Effective PR management allows organizations to build a positive image through strategic communication activities, companies can create a

favorable image of themselves in the eyes of consumers and other interest groups (Lukić, 2023). Also, PR can successfully manage crises, so that at the moment of crisis, PR teams are responsible for timely informing the public and minimizing damage to the organization's reputation (Friedrich-Ebert-Stiftung, 2023). PR enables the organization to achieve a competitive advantage. Organizations that successfully manage their public relations can differentiate themselves from the competition and attract more clients (Vuković, 2021).

3. Public relations management strategies

Effective PR management requires careful planning and implementation of strategies that include the following steps (Lukić & Bujković, 2020; Filipović, 2003):
1. Situation analysis: Understanding the current state of the organization and public perception.
2. Defining goals: Setting clear communication goals that support the organization's mission.
3. Message creation: Development of clear, consistent and targeted messages for different interest groups.
4. Choice of communication channels: Use of traditional media, social networks and direct communication to convey messages.
5. Monitoring results: Evaluating the success of campaigns through the analysis of media coverage, engagement on social networks and feedback (Lukić & Bujković, 2020; Filipović, 2003).

There are different strategies that organizations can apply in their PR activities:
• Anticipation: Proactive shaping of relations with the environment through active communication.
• Adaptation: A reactive strategy that responds to public demands and initiatives.
• Countering: Active or reactive communication used when the organization has a strong position.

Each of these strategies requires careful planning and implementation to achieve the desired results.Placeholder text is used from this point to demonstrate the layout across several pages, including a placeholder figure and table. **Delete all this text before submitting your article**.

4. Trends and challenges in public relations

In recent years, certain trends in the PR industry have been noticeable:

• Digitization - organizations increasingly use digital tools to communicate with the public. Digital PR enables faster interaction and better analysis of user feedback (Smith, 2020).

• Focus on sustainability - with growing awareness of environmental issues, organizations are integrating ESG (Environmental, Social, Governance) activities into their PR strategies to demonstrate social responsibility (Vladimirović, 2023).

• Agility and flexibility - in a world of rapid changes, the ability to quickly adapt to the situation becomes crucial. Organizations must be ready to react quickly to crises and changes in public opinion.

In the modern business environment, PR faces numerous challenges. Namely, the modern business environment brings numerous challenges for PR experts:

• Information overload - In a world where the availability of information is huge, it is difficult to stand out from the crowd. Organizations must develop unique messages that will attract attention (Wilcox et al., 2020). Modern consumers expect transparency and social responsibility from companies, which can be a challenge for PR teams (Meiden, 2021).

• Rapid change in technology - Digitization has changed the way we communicate with audiences. Organizations must use social media and digital tools to stay relevant. Technological progress brings new tools for communication, but it also creates the need for constant learning and adaptation to those tools. The rapid development of technology requires the constant adaptation of new communication tools and platforms (Friedrich-Ebert-Stiftung, 2023).

• Crisis situations - PR teams must be ready to identify potential crises and react quickly to protect the organization's reputation (Lukić & Bujković, 2020). One of the key aspects of public relations management is the ability to respond to crisis situations. risks require quick response and clear communication in order to protect the organization's reputation (Vuković, 2021). According to Lukić (2020), crisis management includes:

- Identification of potential problems before they turn into a crisis.
- Development of detailed response plans in different scenarios.
- Transparent communication with the media and interest groups during the crisis.

Effective crisis response can even improve an organization's reputation if it shows concern for the needs of stakeholders

• Increased public expectations - Modern audiences expect transparency and authenticity from organizations. Failure to meet these expectations can lead to a loss of trust (Tportal, 2022). Consumers today expect transparency, authenticity and social responsibility from organizations (Lamza-Maronić & Glavaš, 2008).

5. The most important instruments for communication in public relations

Public relations (PR) uses a variety of tools and techniques to effectively communicate with target audiences. In the modern business environment, these tools are being developed and adapted to new technologies and trends. The most important instruments for communication in public relations are listed below.

1. Press Releases - Press releases are a basic communication tool that organizations use to inform the media and the public about important events, new products, or policy changes. They serve as a bridge between the organization and the media, enabling the rapid distribution of information. Press releases are one of the most frequently used instruments in PR. They serve to distribute important information about events, new products or significant changes within the organization. An effective press release should answer the basic journalistic questions: "Who?", "What?", "Where?", "When?" and "Why?" (Cutlip & Center, 2020).

2. Social Media - Social media has become a key tool for PR, enabling direct interaction with audiences. Platforms like Facebook, Twitter, Instagram, and LinkedIn allow organizations to communicate in real time, share content, and respond to user comments and questions (Vladimirović, 2023). This form of communication is interactive and provides the possibility of two-way exchange of information.

3. Press conferences - Press conferences are organized events where representatives of the organization communicate directly with the media. This format allows asking questions and providing additional information, which can contribute to a better understanding of the topics covered

3. Digital tools - Digital tools, such as analytics software (eg Google Analytics) and media monitoring tools (eg Meltwater), help organizations track the effectiveness of their PR campaigns. They enable the analysis of audience engagement data, which helps to adjust communication strategies.

4. Content Creation - Content is critical to the success of PR strategies and is the heart of any PR strategy. Organizations use a variety of content formats, including blogs, videos, infographics, and visuals to capture the attention of their audience. Tools like Canva allow even smaller businesses to create professional content to capture the attention of their audience and deliver their messages in an engaging way (Wilcox et al., 2020).

5. Media Databases - PR professionals often use media databases to identify relevant journalists and media to distribute their releases. These databases allow for personalized communication instead of mass distribution, thus increasing the likelihood that the message will be received.

6. Personal communication - Personal approaches, such as lobbying or direct meetings with key stakeholders, remain important tools in PR. This type of communication allows organizations to build stronger relationships with decision makers and other important stakeholders

7. E-mail marketing - E-mail marketing is another traditional but effective tool for communicating with the audience. By using platforms like MailChimp, organizations can send targeted announcements and newsletters that are tailored to the interests of their users (Tportal, 2022).

8. Organizing events and promotions - Organizing events such as conferences, workshops or product promotions provides direct interaction with the audience. These

events enable the personal presentation of the brand and the creation of a positive image through direct communication

Media monitoring is key to analyzing the success of PR activities. This process includes monitoring brand mentions in the media, analyzing feedback and identifying trends that can influence communication strategies.

6. Measuring the success of public relations

Measuring the success of public relations requires a comprehensive approach that combines quantitative and qualitative metrics (Grunig & Hunt, 2019). The success of public relations (PR) is measured through various metrics and indicators that enable the evaluation of the effectiveness of communication strategies. The main ways in which success in PR can be measured:

1. Media views - Monitoring the number and quality of media views is the basic way to measure the success of PR campaigns. This includes analysis (Cutlip & Center, 2020).:

• Quantities: How many times was the organization mentioned in the media?

• Quality: Are these views positive, negative or neutral? This aspect helps in understanding public perception.

2. Social media engagement - Social media has become a key platform for PR. Measuring success includes (Wilcox et al., 2020):

• Interactions: Likes, comments, shares and follower growth tracking.

• Availability: How many users have seen the content? These metrics help evaluate the reach and impact of campaigns

3. Organized events - If organized events are part of the PR strategy, their success can be measured through:

• Number of participants: How many people attended?

• Feedback: Surveying participants about their satisfaction and perception of the event

4. Connecting with target groups - Success can be measured through an organization's ability to establish connections with key stakeholders, such as influencers, journalists and relevant communities. This indicator includes:

• Collaboration: Have new collaborations or partnerships been achieved?

• Referrals: How many new clients or associates came through referrals

5. Feedback Analysis - Collecting and analyzing feedback from the public and clients helps in understanding how messages are perceived. This may include:

• Surveys and interviews: Understanding attitudes and opinions about a brand or organization.

• Online reviews: Monitoring comments and ratings on platforms such as Google Reviews or Trustpilot

Measuring the results created and implemented with the target audience is a mandatory activity that is the responsibility of marketing managers in organizations. This activity is crucial, given that the success of the implemented activities related to public relations is measured based on established parameters. Based on the achieved results, the corrections that need to be implemented in the entire marketing sector of the company and especially in the part related to entering the target market are determined. Also, the measurement specifies the further actions that need to be implemented, in order for the company to achieve and maintain a competitive advantage, which is of the greatest importance for survival on the market, which is characterized by modern, highly variable business conditions.

Conclusion

Public relations management plays a key role in the modern business environment. Through careful planning of communication strategies, use of modern technologies and effective response to crisis situations, organizations can build the trust of their interest groups and ensure long-term success. As technology advances and consumer expectations grow, PR will continue to evolve as an integral part of business success, meaning PR will need to adapt to new challenges and opportunities.

In today's business environment, the success of public relations depends on the ability of organizations to use a variety of tools to effectively communicate with different audiences. The combination of traditional and digital tools allows organizations to build strong relationships with their stakeholders and adapt their strategies according to changes in the market. These instruments not only facilitate communication but also help measure the success of PR campaigns, which is crucial for the continuous improvement of relationship strategies. with the public.

Measuring public relations success requires a comprehensive approach that combines quantitative and qualitative metrics. Through analysis of media coverage, engagement on social networks, organized events, engagement with target groups and feedback, organizations can get a clear picture of the effectiveness of their PR strategies and adapt them for future campaigns.

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Reactualization of the Principles of New Public Management as a Contemporary Administrative-Legal Doctrine

Suan Islamović and Jasmin Hušić

Faculty of Law, University of Bihać, Bihać, Bosnia and Herzegovina

E-mail: suan.islamovic@gmail.com

Abstract. As a result of broader neoliberal movement, New Public Management represents the most significant international attempt to align labour law standards in the public and private sectors, with a particular focus on those related to market competition. This modern doctrine traces its origins to the 1980s and has already been implemented in some of the important Western countries. Due to its global recognition, the literature treats it as one of the most recognizable contemporary trends in the development of administrative and civil service law. In this paper, the authors examine the fundamental standards of New Public Management, emphasizing the applicability of this modern administrative-legal doctrine's principles.

1. Introduction

The scientific and professional examination of New Public Management (hereinafter also: NPM) as a contemporary administrative-legal doctrine is not the exclusive domain of legal scholars or the legal profession. As an innovative reform project, NPM necessitates a multidisciplinary approach in which economists, political scientists, sociologists, IT specialists etc. Even psychologists play significant roles - particularly in adapting work and organizational processes to individual employees within state structures. In any comprehensive analysis of NPM, its core components and its influence on national systems, particular contributions are required from experts in public law, public policy and public management.

Although legal scholarship has already addressed this topic extensively, it remains useful to revisit and refine the relevant principles, especially given the inherently dynamic nature of the doctrine in question. This paper examines the principles of New Public Management and their renewed significance within contemporary administrative-legal frameworks. Employing normative and comparative legal methodologies, the analysis will explore the origin, development and ideological foundations of the NPM movement, with particular focus on its core principles and the degree and models of implementation across various national contexts. Ultimately, the paper will examine NPM's interaction with national (self-)governance structures. The concluding section offers a brief overview on the potential integration of appropriate

NPM principles into the administrative-legal system of Bosnia and Herzegovina, with special attention to the impact of the country's existing constitutional-legal framework on the concept of efficiency at the level of local self-government units.

2.The concept, ideological background and development of New Public Management

New Public Management does not merely signify a declarative or linguistic shift from the traditional term administration to management. Rather, it reflects substantial transformations in the functioning of the state apparatus, driven by evolving economic and social dynamics shaped by globalization and globalized interactions. NPM embodies a deliberate alignment with private-sector economic values, with particular emphasis on flexibility and efficiency - two core concepts that have fundamentally reshaped the global understanding of traditional work-related norms and values.This concept is "largely derived from private sector management practices and entrepreneurial characteristics, and it implies that public administrations operating in a business-like manner will be more effective and efficient, while citizens - treated as consumers - will experience greater satisfaction with public services". [1] The aforementioned principles also serve as the foundation for the continuation of this research, based on the hypothesis that national administrations will operate more efficiently and effectively if they adopt the established operational models of the private sector. Public servants continue to 'serve' the interests of citizens, but within the framework of the new standards imposed upon them.

The flexibilization of labour relations within national systems is a consequence of globalization and, as such, constitutes an economic and social necessity in the modern era. It is evident that this trend has its roots in the American legal-political system, which is grounded in neoliberal philosophy -characterized by limited state intervention, the principle of pacta sunt servanda and the ideological paradigm of laissez-faire. This clearly leads to the conclusion that the core principles and values of New Public Management are founded on the hypothesis that **"**a greater market orientation in the public sector will result in higher cost efficiency for governments without negative consequences for other goals or considerations". [2] Inspired by the standards and operational logic of the private sector, NPM is fundamentally oriented toward cost-efficiency and economic rationalization. However, its ultimate objective lies in adapting this model of governance to align with the complex and often competing legal, political, economic and social priorities of the modern nation-state. Consequently, states with historically developed and institutionalized free-market systems hold a structural advantage in achieving the goals of NPM. In contrast, countries with closed national markets or those undergoing transitions between two distinct economic systems often encounter significant institutional and practical challenges when implementing NPM-oriented reforms, even when political will is present.

The doctrinal inspiration for New Public Management comes from the teachings offered by Margaret Thatcher and Ronald Reagan. Today, the countries that have aligned their public policies with the principles of NMP are primarily traditional liberal democracies [3], which is, in any case, a logical consequence when considering the

countries represented by the two aforementioned statespersons. The concept outlived the political career of Margaret Thatcher, who became Prime Minister of the United Kingdom in 1979. Research from 1996 indicates that, on a global scale, only New Zealand surpassed the United Kingdom in the number of reform initiatives undertaken. Subsequently, the British model of NPM became a reference point for numerous countries within the Organisation for Economic Co-operation and Development (OECD), and it is noteworthy that this model most distinctly embodies neoliberal thought. [4] Once the foundational conceptual elements of NPM and the ideological backdrop that shaped its development are outlined, it becomes clear that this process is deeply intertwined with the forces of globalization and the liberalization of the global market. Anglo-Saxon countries, as the pioneers of this initiative, saw an opportunity to claim their position within the evolving global order. The United Kingdom is especially prominent here as it was deeply affected by decolonization following World War II, eventually culminating in an economic crisis. From the standpoint of administrative and legal sciences, it is evident that changes in the functioning of the national state's bureaucratic apparatus are not isolated reforms. Rather, they are a consequence of the broader structural changes initiated by NPM. More precisely, these shifts represent an alignment with what academic discourse has defined as a necessary response to the evolving needs of modern governance. Based on this overview, the foundational conditions for examining the principles and extent of NPM implementation across different national systems have been established. This will serve as the basis for evaluating the impact of NPM on national administrative structures.

3. The principles and level of implementation of New Public Management

The absence of market competition in the public sector is an undeniable reality that certain countries recognized over fifty years ago, and it is this very fact that constitutes one of the primary reasons for the lack of competitiveness within the state across numerous sectors. The flexibility of labour in the private sector, driven by private capital, has become dominant in all economic spheres, from local and regional levels to the global stage. In this context, New Public Management can be seen as a *sui generis* response from some Western countries to the tectonic shifts in global production, service, and supply chains -processes over which the nation-state has minimal (if any) control. Overall trends in public sector reforms in developed national systems reveal that these states are embracing the concepts of deregulation, privatization and marketization, while simultaneously strengthening various functions of the state, a strategy that is methodologically complementary to the goals of the private sector.

It is important to note that there is no universal formula for the (comprehensive) implementation of New Public Management in the national system; rather, the degree of alignment is assessed *in concreto*. Thus, Nordic countries, as leaders in the realization of the 'welfare state', aim to direct the mechanisms of NPM precisely towards strengthening elements of that orientation. On the other hand, as the most prominent representative of neoliberal doctrine, the United States applies the principles of NPM even in the areas of national security, through the outsourcing system in the operations of the armed forces, intelligence and security agencies and similar sectors. Private military companies and private security agencies are not unfamiliar to the United

Kingdom, and they essentially serve as a means to reduce bureaucratic barriers and generally lessen the level of control over the various activities these companies provide. These examples confirm the initial premise about the absence of a universal formula for the implementation of NPM in the different structures of national states.

Without further problematizing the model of implementing New Public Management in national states, it is important to highlight several countries that have achieved the highest level of alignment with the mechanisms of this contemporary movement. NPM is a neoliberal project which, through labour flexibilization in the public sector, has induced numerous changes in the system of rights, duties and responsibilities of public servants, as well as in the overall functioning of national bureaucratic structures. Since the 1980s, NPM has been introduced in Anglo-Saxon legal systems through various models and mechanisms: the United Kingdom, the United States, New Zealand and Australia. Although these countries are **concurrently** leaders in the reform and institutionalization of NPM at the national legal and political levels, countries like Sweden, Germany, the Netherlands and Sweden should not be overlooked, as they too have adopted part of the management standards of this modern doctrine within their national structures. While some Latin American countries and South Africa are also mentioned in the literature, two of the four 'Asian Tigers' (Singapore and South Korea) have reached a high level of implementation of NPM, which suggests that this is not a local or regional movement, but a contemporary trend in administrative and civil service law whose principles have been realized through various methodological approaches in countries across different continents.

When it comes to countries in the region, the Republic of Croatia, as a member state of the EU, has probably achieved the highest level of implementation of New Public Management standards, although this level is still incomparable to what has been accomplished by the aforementioned countries with traditionally strong democratic systems. As for the local public sector and the dynamics of adopting business practices from the private sector promoted by NPM, the literature highlights “the limitations of financial and administrative capacities of localities, arising from insufficient fiscal and managerial decentralization of the local public sector in Croatia”. [5] Therefore, in this context, it is impossible to provide comprehensive conclusions without deeper comparative analyses of all existing local self-government units in this country. On the other hand, it is evident that countries in transition and post-transition periods face visible challenges in adapting to NPM standards. Systemic and structural changes in the functioning of the entire state apparatus, and consequently in what is known as public administration, cannot solely be achieved through a 'top-down' approach. Numerous factors must be taken into account, particularly the prevailing legal-political context and the shape of the existing legal tradition. In any case, national capacities for aligning with inevitable or required changes are not solely an economic issue. This is demonstrated by the aforementioned countries that have taken a leading role within the global legal and economic order in recent decades. The final section of the paper focuses on the relationship between NPM standards and national (self-)governance structures, offering a brief overview of the existing institutional arrangements in Bosnia and Herzegovina.

4.New Public Management and national (self-)governance structures

The concept of New Public Management is closely linked to the idea of *good governance*, which, as a political concept, is based on principles rooted in the private sector. This does not imply the complete exclusion of the state's role in various processes, but rather a reformulation of its role in market dynamics: promoting market competition and transparency with an emphasis on deregulation and re-regulation. Labour market liberalization and the easing of administrative constraints across various sectors represent some of the most significant outcomes of deregulation, understood as the systematic rollback of state-imposed regulations. In principle, the concept of deregulation is intended to facilitate private sector operations and enhance overall business efficiency, which in turn reduces the need for expansive state apparatuses and the administrative personnel traditionally responsible for regulatory oversight. Reregulation is expected to produce similar effects, as it grants the private sector significantly greater autonomy in developing its own rule-making systems - functions that have historically fallen within the competence of public administrative structures. The structural-bureaucratic, personnel, functional and other innovations introduced by NPM point to numerous consequences for the public sector's functioning: its reduction, a simplified public procurement system, fewer employees, the introduction of flexible work arrangements, financial savings in all segments and everything that can make the public sector more economical and efficient. When viewed in their entirety, the changes introduced by NPM in contrast to traditional public administration system are outlined in the following chart:

Table 1: Public Administration vs New Public Management [6]

No.	*Elements*	*New Public Management*	*Traditional Public Administration*
1	Government organization	Break-up of traditional structures into quasiautonomous units	Services provided on a uniform basis operating as a single aggregated unit
2	Control of public organizations	Hands-on professional management with clear statement of goals and performance measurement	Control from the headquarters through the hierarchy of unbroken supervision and checks and balances
3	Control of output measures	Stress results and output control rather than procedures	Control on inputs and procedures
4	Management practices	Using private sector management style	Standard established procedures throughout the service
5	Discipline in resources use	Check resources demand and 'do more with less'	Due process and political entitlements

Through the restructuring of traditional bureaucratic methods in the functioning of public administration, the standards of New Public Management causally affect the position and regulation of the public servants' labour status, which is particularly evident through the 'KPI concept' (Key Performance Indicator). Beyond the various innovations it brings to the operations of state administration, KPI concept serves as a methodological tool for measuring the productivity of individual employees. Thus, in addition to other numerous innovations in operational work, the rationalization of financial expenditures, the functioning of marketing and so on, the KPI concept sets annual financial and other goals for the entire public administration body and ultimately defines the methods for measuring the results of each individual employee's work. These measurements of individual employee efficiency on an annual, quarterly, monthly, weekly and sometimes even daily basis can ultimately result in various forms of incentives if the employee demonstrates productive performance: days off, monthly variable salary components, quarterly/annual bonuses and other benefits. Although this is a system that has been standardized in the private sector for decades, it is clear to what extent the principles of New Public Management can 'shake up' traditional bureaucratic structures, which, it seems, mainly provide employment stability for public servants.

Consequently, the traditional bureaucratic structures, which are based on Max Weber's strict hierarchy and process formalization, are changing. With the gradual introduction of market mechanisms and a decentralized decision-making system, the role of public servants is also changing, as they are compelled to use the tools of modern management. A parallel consequence is less stable job positions and a higher level of unpredictability in career paths. However, this does not necessarily have to be a negative consequence for public servants in any national system, provided that the mechanisms of New Public Management are properly articulated and directed toward reforms that will make national administrative structures more efficient, while also enabling public servants who wish to invest in their education and advance in their careers to do so. Just as there is no universal formula for the implementation of NPM at the national level, there is no one-size-fits-all approach to enhancing the efficiency of public servants' work. This is indicated by KPI standards, which are strictly individualized not only for organizational units but also for each individual public servant. Before drawing the conclusions of this research, it is necessary to mention some key characteristics of the Bosnian-Herzegovinian system, which is currently undergoing a (post-)transitional period.

4.1. Overview of system in Bosnia and Herzegovina

In the case of Bosnia and Herzegovina, it is clear that traditional bureaucratic principles remain deeply embedded at the level of the state, the entities, the Brčko District and the cantons within the Federation of Bosnia and Herzegovina. Nevertheless, this does not exclude the potential for introducing key principles of New Public Management at both regional and local administrative levels. For example, Article 4 of the Law on the Organization of Administrative Bodies in the Federation of Bosnia and Herzegovina explicitly emphasizes the principle of efficiency, which is a cornerstone of NPM. The rationalization of public spending spans a wide array of sectors, processes and sub-

processes within administrative structures at various levels. From the management of movable and immovable assets, oversight of public procurement and control of energy expenditures to payroll optimization and organizational restructuring, notable improvements can be achieved - particularly at the level of cities and municipalities as units of local self-government. However, a fundamental challenge remains in the existing internal constitutional and legal framework, where entity boundaries are not shaped by natural features such as rivers or mountains, nor by the socio-economic needs of the population in specific geographic regions. The imposed constitutional order does not serve the principles of efficiency, resulting in a range of further complications. For instance, the concept of good and flexible governance is fundamentally incompatible with a rigid bureaucratic system, which, unfortunately, remains a defining feature of the current framework.

Entity boundaries play a crucial role in determining the structure and number of local self-government units in Bosnia and Herzegovina. Some illustrative examples include the municipality of Istočni Drvar, which recorded a population of 34 in the 2013 census; Petrovac with 361 residents; Istočni Mostar with 257; Dobretići with 754; Foča-Ustikolina with 2,213 and Pale-Prača with 904 residents, among others. According to the provisions of the Law on the Principles of Local Self-Government, municipalities and cities within the Federation of Bosnia and Herzegovina are organized under a single-type model, meaning they hold "the same legal status regardless of specific characteristics such as population size, territorial scope, level of economic development and similar factors". [7] In addition to limiting the development potential of local communities, such a framework simultaneously disregards the principle of cost-effectiveness advocated not only by New Public Management, but also by the applicable federal legislation. In this context, any further analysis is closely tied to the initial assumptions concerning the dysfunctional, purposeless and inefficient systemic organization of local self-government units in Bosnia and Herzegovina, considering that the overall administrative system of the country can simply be described as "overly complex, expensive and inefficient". [8] The number and role of local self-government units undermine the concept of good governance at higher levels of authority, given their interdependence in administrative functioning (e.g., cities and cantons). No general assessment can be made regarding the efficiency or the level of implementation of NPM's standards at the entity or cantonal levels; on the contrary, as was the case with local self-government units in the Republic of Croatia, this topic must be approached through case-by-case analysis.

5.Concluding remarks

For nearly five decades, economically developed countries have introduced various reforms within their national systems, which are essential components of New Public Management, particularly in terms of flexibilizing administrative and civil service law. Nevertheless, the extent of their implementation remains below the level achieved in the private sector. The idea of structural changes, through which systemic reorganization of traditional bureaucratic models in the functioning of public administration occurs, remains realized only in a limited number of countries

worldwide. It is difficult to provide a universally acceptable answer regarding the efficiency of national administrative systems that may decide to implement New Public Management. Still, the findings of this research suggest that countries that have implemented New Public Management within their national systems are among the most developed in the world, both in terms of economic capacity and the level of development of human rights and fundamental freedoms. The basic issue is precisely the question of national capacities for realizing the objectives of this doctrine, and these national capacities are not solely related to economic power and the system of governance, but also to the intrinsic legal culture. In this regard, NPM, like any other legal and economic movement, is not inherently positive or negative. It can be effective and desirable for a national system if used as a tool to strengthen the *rule of law* through the acceptance of inevitable economic, social and other global changes. On the other hand, its effects can be negative if its institutions are abused for the realization of rough capitalist goals based on Machiavellian ideology. When it comes to the national context of Bosnia and Herzegovina, the primary obstacle to implementing the relevant principles of New Public Management as a contemporary administrative legal doctrine is the complex constitutional system, which effectively disregards the fundamental principle - the principle of cost-effectiveness.

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Implusive buying as a factor in personal finance management

Arnela Nanić, Irnesa Kujundžić and Hana Šiljdedić

Faculty of Economics at the University of Bihać, Bihać, Bosnia and Herzegovina

E-mail: arnela.nanic@efbi.unbi.ba

Abstract. Impulsive buying, as a specific consumer behavior, is related to the influence of situational factors on the decision-making process and purchasing decisions. Impulsive consumers often face challenges in managing their personal finances, which can jeopardize their financial well-being and, consequently, affect their quality of life. This paper analyses impulsive consumer decisions as a factor in the personal finance management process. The purpose and objective of this study are to explore how impulsive consumer decisions impact personal finance management and whether and how consumers can be influenced to ensure their financial stability. The objectives of this study are to identify the key causes of impulsive consumer behavior, determine the main factors influencing successful personal finance management, establish a cause-and-effect relationship between these two concepts, and analyze their implications for an individual´s quality of life. Furthermore, the study aims to examine the consequences of impulsive consumer behavior on financial well-being and explore how awareness of actual needs and the level of financial literacy affect purchasing success and financial health. The research will be conducted using a structured survey questionnaire administered to a convenience sample of respondents with diverse demographic characteristics. For the collection of primary data, Google Analytics will be utilized, and the survey will be distributed online. The objective of this research is to contribute to a better understanding of this issue and provide concrete recommendations for improving consumers´ financial well-being through strategic management of personal spending.

1.Introduction

In modern society, impulse buying has become an increasingly prevalent phenomenon that significantly impacts how individuals manage their personal finances. Given the rapid development of consumer culture and easy access to consumer goods, many consumers face the challenge of making rational financial decisions. Impulsive purchasing decisions, which are unplanned, can have a serious impact on an individual's long-term financial stability.

Impulse buying is defined as the act of purchasing products or services without prior consideration of actual needs or financial consequences. This form of spending is usually driven by emotions, immediate desires, or social influences rather than rational analysis or long-term planning. Various factors, such as psychological biases, social pressures, advertising strategies, and even current emotional states, play a key role in shaping impulsive consumer behavior.

The main hypothesis is formulated based on the research problem, subject, and objectives, and it states: *"Impulsive consumer decisions result in poor personal finance management and long-term financial instability."*

Based on the main hypothesis, the following auxiliary hypotheses are proposed in the study:

- The lack of budgeting and financial planning increases the tendency toward impulse buying and makes long-term personal finance management more difficult.
- A high level of financial literacy helps reduce impulse buying and enables better personal finance management.
- Large discounts and promotional offers encourage impulse buying, often at the expense of rational personal finance management.
- Greater product availability due to digitalization and online shopping increases the tendency toward impulse buying and personal financial problems.

2. Theoretical framework of the study

2.1 Situational factors of consumer behavior

A large number of different factors influence behavior when making a purchase decision. A significant group of these factors is made up of situational factors, which, as the name suggests, influence the purchase decision at a certain moment of the final decision, and can change the final decision at the last moment before the purchase itself. Situational factors that influence the final purchase decision include the physical appearance, i.e. the interior of the point of sale itself, or the visual impression of the website in the case of online shopping; the presence of other people during decision-making, their advice, criticism and recommendations; the time we have available for the decision as well as the purchase motive itself; previous psychological state of the purchase decision maker.

Consumer behavior is an interactive relationship between knowledge, feelings, behavior and the environment in which the behavior takes place (Grbac, B., Lončarić, D., 2010, p.18). Precise, timely and continuous monitoring of the purchase process, identifying factors in that process and distinguishing between special types of purchase decisions are of essential importance for the success of every company (Tihi, B., Čičić, M., Brkić, N. et.al., 2006, p.155).

Situational influences encompass all current conditions that occur in the environment at a specific time and space (Milas, G., 2007, p.161). Situational influences can be defined as factors associated with a specific situation, specific time and space and are entirely independent of the characteristics of the consumer, the object and the service being purchased (Kesić, T., 1999, p.93).

Situational factors include physical surroundings, social surroundings, temporal perspective, task definition and antecedent states (Belk, 1975, p. 152):

- Physical surroundings refer to geographical and institutional location, decor, sounds, aromas, lighting, weather and visible configurations of merchandise or other material surrounding the stimulus object.
- Social surroundings include the presence of other persons, their characteristics, apparent roles and interpersonal reactions.
- Temporal perspective is a dimension of situations that may be specified in units ranging from time of day to season of the year.
- Task definition refers to the features of situations, such as an intent or requirement to select, shop for or obtain information about a general or specific purchase.
- Antecedent states are momentary moods or conditions of buying such as acute anxiety, pleasantness, hostility, cash on hand, fatigue and illness.

2.2 Impulse buying

Impulse buying is actually a spontaneous and unplanned decision by consumers to purchase products or services that were not originally planned on the shopping list. The decision to buy impulsively is most often made under the influence of factors from the external environment such as the design of the store or window display, the recommendation of the person accompanying us when shopping, lack of time to think, stress, sadness, low mood and numerous other psychological states in which the consumer is at the moment of decision.

Impluse buying occurs when the person experiences a sudden urge that he or she cannot resist. (Solomon, et.al., p.324). Solomon (2002, p.303) further categorises consumers according to the degree of manifestation of impulse buying behaviour:

- *planning consumers*, who always decide in advance what, how much and which brands they will buy;
- *partially planning consumers*, who either choose only the category, or only the amount of product to buy; and
- *impulsive buyers*, without any prior shopping plan

In the case of unplanned shopping, one cannot speak of any degree of pre-purchase involvement of the consumer. In other words, everything happens at the moment of purchase and on the spot, in the store itself. On the spot, in the store, both the product and the brand of the product are chosen. Then, on the spot, a decision is made about other details - design, payment method, etc. (Čičić, M., Kukić, S., Husić, M., 2009, p.188). Urge to buy impulsively has recently been described as a complex, sudden and

enjoyable purchase occurs instantaneously and without thinking, any measure of the other considerations (Kazempour, Y., Lotifizadeh, F., 2017, p.13). The findings of this research, in adition to showing the positive effect of urge to buy impulsively on the behaviour of impulsive buying, show that with increase in an urge to buy impulsively and suddenly, the performance of level of impulse buying will be increase (Kazempour, Y., Lotifizadeh, F., 2017, p.23). Unplanned buying is defined as the purchase of a product that was not planned prior to entering the store. In the context of study of this autors, unplanned buying does not necessarily refer to the purchase of products to satisfy needs that were recognized but unretrieved at the time the purchase plan was developed (Park, C.W., Iyer, E.S.,Smith, D.C., 1989, p.423-424). The study of other research (Kursan, I., Mihić, M., 2010,p.58) found that promotional activities, friendly and skilful staff, store location, and agreeable aroma of some food products can generally influence them to buy on impulse, wehile their shopping companions can generally affect their buying behaviour and choice, but can only to some extent induce them to buy on impulse.

2.3 Management of personal finances

In the last decade, personal finance, as a part of finance, has gained importance due to the growing interest in researching the financial literacy of citizens. Managing personal finances is a daily routine that sometimes requires a lot of effort, if family members are not financially literate.

Personal finance refers to financial planning and control of personal financial flows - inflows and outflows of cash with the aim of maximizing individual well-being (Joksimović,Ž., 2018, p.70). Personal finance includes all financial decisions and activities of an individual or household, including budgeting, investing, retirement planning and protection against financial risks (Kapoor, J. R., Dlabay, L. R., & Hughes, R. J., 2012, p.4). For quality management of personal finances, it is enough for an individual to have financial knowledge that will enable him to control financial flows and to have a clear overview of the financial situation and success based on a previously defined financial plan and budgeting. The key components of personal finance that achieve financial well-being are: income, budgeting, savings, investing, debt management, insurance and retirement planning. Regarding the planning and management of personal finances, it is necessary to primarily assess the present before creating a financial plan. Personal finance management is much more than money management. It implies a pattern that allows you to use your limited time and available money in the best possible way, whereby financial planning plays a fundamental role.

According to L.Peters, if you don't know where you are going, you will most likely end up somewhere else (Santini,G., Bebek, S., 2005, p.6). Before any financial plan, it is necessary to assess your financial situation and set realistic goals. The financial plan includes an analysis of the current situation, a personal investment or savings strategy and the setting of financial goals. It is especially important to have a clear picture of cash flows, i.e. how much you spend, where the money comes from and where it goes, and how much is left at the end. The budget can be made on a daily, monthly and yearly basis and for different purposes. It consists of receipts (salary, pension, other income)

and expenses (basic living expenses, luxury and other expenses). The process of creating a budget begins with the classification and allocation of money to receipts and expenditures, continues with spending control, and ends with an assessment and adjustment of the existing situation. Budgeting is essential for cost planning because only in this way can an individual determine how much money he needs to cover expenses, which cost items can be eliminated or reduced, and realize a positive difference between income and expenses that will ultimately result in savings or investment.

Financial plan control is the last step in financial planning. It involves reviewing everything we were supposed to do and coming to a conclusion about whether we did everything as planned. Financial planning does not end at this stage, but is a dynamic process that continues continuously (Ivanov, M., Barbić,D., Lučić, A., 2019, p.159).

2.4. Financial literacy

Efficient management of personal finances is a key aspect of an individual's financial stability. Financial literacy, ability to budget and awareness of personal income and expenses play a crucial role in making rational financial decisions. However, in the modern consumer society, where digital shopping and the availability of credit are on the rise, controlling costs becomes an increasing challenge. Financial literacy is a relatively new concept that is related to the management of personal and business finances, and generally to the attitude towards money. Many authors define financial literacy as the skill and ability to manage money and knowledge of financial products.

The Organization for Economic Cooperation and Development (OECD) defines financial literacy as knowledge, understanding of financial concepts and risks, and includes the skills, motivation and confidence to apply such knowledge and understanding with the aim of making effective decisions in a number of different financial contexts in order to improve the financial well-being of individuals and society and enable participation in economic life (Roth et al. 2014, p. 5). In simpler terms, being financially literate implies rational planning of the household budget, separating the part for saving and the part for investing (Kujundžić,I., 2023, p. 50). Financial literacy solves problems and creates money. Money without financial literacy is money that will disappear quickly (Kiosaki,R.T., 2018, p.110).

Managing money is not easy and is not a skill that every individual understands properly. For young people and children, financial literacy should be part of the general literacy of the population, which includes knowledge of how to correctly judge between two risky investments, to be able to correctly analyze the current situation and predict the future, and to rationally allocate monthly income according to one's needs.

2.5. Overview of previous research

Financial literacy plays a key role in how individuals manage money and make financial decisions. Lusardi and Mitchell (2011) state that high financial literacy positively affects the ability to budget and make informed decisions about spending. This paper considers the influence of financial literacy on decision-making about pension funds, but also provides broader insights into the importance of financial literacy. The paper emphasizes the importance of financial literacy for making rational decisions about

savings and investments for retirement. Increasing financial literacy can help people recognize long-term financial challenges and properly prepare for retirement. Also, additional educational efforts are needed to reduce the differences in financial literacy between different social groups. This work may provide an important basis for understanding how financial literacy affects other areas of financial behavior, including impulse purchases and personal financial management. Conversely, research by Joo and Grable (2004) indicates that low financial literacy can increase the tendency to make impulse purchases, as such individuals do not recognize the long-term consequences of their spending habits and tend to spend more than they can afford.

Lichtenstein et al. (1995) reveal that high incomes can be associated with greater tendencies towards impulse purchases, because people with higher incomes have more space for such transactions, but also a higher probability of using credit products. Financial literacy alone, although important, is not enough to ensure long-term good money management. It is necessary to take into account emotional, cognitive and social aspects, as well as apply educational strategies that will enable people to recognize these factors and better manage their finances.

On of the research examine whether financial education has either direct or indirect potential effect on financial satisfaction, a measure of subjective financial wellbeing. The results suggest that financial education has multiple benefits for improving financial wellbeing such as facilitating knowledge acquisition, enhancing confidence in knowledge and ability, and encouraging action taking. The findings suggest that to improve consumer financial wellbeing, financial education may be more effective in helping consumers raise confidence in financial knowledge and engage in desirable financial behaviors than in obtaining objective knowledge (Xiao, J.J., Porto, N, 2017, p.817).

3. Methodology, analysis of research results and research limitations

For the purposes of the work, a quantitative research was conducted, implemented using a survey questionnaire that was created through a Google Forms form. In the research process, a structured questionnaire was applied to a convenience sample of respondents. The aim of this research was to examine the impact of impulsive consumer decisions on personal finance management and long-term financial stability. Considering the ubiquitous phenomenon of impulse buying and its potential impact on the financial health of individuals, the research focuses on the analysis of the factors that contribute to this type of consumption, as well as the possibilities for its reduction through better financial planning and literacy. The research was conducted in the period from February 18, 2025 to March 24, 2025. year.

The questionnaire was distributed via e-mail and social networks. For the purposes of this research, a survey was conducted on a sample of 158 respondents with different demographic characteristics, which enabled the collection of data on spending habits, the level of financial literacy, as well as factors that encourage impulse buying. The

survey included questions about regular income, monthly income, debts, as well as the place and motives for impulsive spending. Also, a Likert scale was used to assess the frequency of impulse purchases and their impact on financial plans.

The methodological framework of the research includes a quantitative approach that enables the analysis of the sample through descriptive statistics, correlations, as well as testing the set hypotheses. The results will enable a deeper understanding of the relationship between impulsive consumer decisions and financial behavior, and provide useful guidelines for future strategies in education and prevention of financial problems caused by impulse purchases. The research was conducted with the aim of investigating spending habits, the impact of impulse purchases on personal finances, as well as the factors that shape impulse spending among consumers. The survey collected data on the demographic characteristics of the respondents, their financial habits, as well as their attitude towards impulse purchases. In this subchapter, the key findings that we arrived at based on the analysis of respondents' answers are presented.

Table 1. Sample structure

Category	The most common answer	N	%
Age group	18-24 years old	82	51,9
	25-34 years old	24	15,2
	35-44 years old	28	17,7
Sex	Female	141	89,2
	Male	17	10,8
Level of education	Medium	68	43
	High	69	43,7
	Other	21	13,7

Source: creation of the author

The respondents were divided according to different demographic categories. The largest number of respondents belonged to the age group of 18 to 24 years (82/158), which is 51.9% of the entire sample. This data suggests that younger people are more prone to impulsive purchases, which is in line with previous research that shows that younger generations have less developed habits in managing personal finances. It is interesting that women made up the majority of the sample, with 141 respondents (89.2%), which may indicate specific consumer habits that can be further investigated. The majority of respondents have secondary education (43%) and higher education (43.7%).

The next group of questions sought to investigate spending habits, debt and the impact of impulse purchases on personal finances in accordance with the respondents' monthly income. The results of the research are presented in Table 2.

Table 2. Financial characteristics and habits of respondents in relation to impulse buying

Question	The most common answer	N	%
Do you have a regular monthly income?	Yes	108	68,4
What is your monthly income?	Less than 500 KM	61	38,6
	1.000-2.000 KM	56	35,4
Do you have debts (minuses) on credit cards or loans?	No	126	79,7
Where do you most often make impulse purchases?	In physical stores	91	57,6
Does the possibility of online shopping further increase unplanned/impulsive purchases?	Yes	128	81
What most encourages you to make impulse purchases?	Discounts and promotions	111	70,3

Source: creation of the author

The majority of respondents (68.4%) have regular monthly income, while the remaining 31.6% do not have a stable source of income, which can affect the way they make financial decisions. The largest percentage of respondents (38.6%) have a monthly income of less than 500 KM, while 35.4% earn between 1,000 and 2,000 KM. These data indicate a relatively low level of income, which can contribute to poorer financial planning and increased sensitivity to impulse purchases. The majority of respondents (79.7%) do not have credit card debt or loans, which suggests that although they tend to make impulse purchases, they do not use credit financing sources too much. Respondents most often make impulse purchases in physical stores (57.6%), while the rest are subject to online shopping. This may indicate that the physical environment and product exposure in stores play a significant role in impulsive decision making. As many as 81% of respondents believe that the possibility of online shopping further increases impulse purchases, which confirms the hypothesis that digitalization facilitates unplanned spending and can contribute to financial instability. The largest number of respondents (70.3%) cite discounts and promotions as the main incentive for impulse shopping. These data indicate a strong influence of marketing strategies on

consumer decisions and confirm that promotions play a key role in increasing unplanned spending.

The next question was formed by a Likert scale (1 – Never to 5 – Very often) where respondents were asked to rate their level of agreement with certain statements about impulse buying. On the basis of a Likert scale, respondents rated the frequency of their impulse purchases. The results showed that the majority of respondents (37.9%) sometimes buy unplanned products, while 27.8% of respondents stated that they often do the same. Also, 47.5% of respondents stated that they later regret impulse purchases, which indicates that impulsive purchases are not always rational and leave a negative impression on the financial situation of individuals. For 31% of respondents (37.4% sometimes, 17.7% often), impulse buying disrupts their financial plans, which indicates that impulsive spending has a significant impact on the long-term management of personal finances.

Table 3. The frequency of impulse purchases and their impact on financial plans according to respondents' answers

Question	Never	Rarely	Sometimes	Often	Very often
I often buy unplanned products.	3,2%	22,8%	37,9%	27,8%	8,3%
Later I regret the impulsive purchase	10,1%	22,2%	47,5%	13,3%	6,9%
Impulsive shopping disrupts my financial plans.	8,2%	23,4%	37,4%	17,7%	13,3%

Source: creation of the author

With the following questions, respondents were asked to rate their level of agreement with certain statements regarding financial behavior and habits. Each statement uses a Likert scale (1 – Strongly disagree to 5 – Strongly agree). 36.7% of respondents stated that they regularly plan their budget, while 38% of respondents admitted that they often exceed the planned budget due to unplanned purchases. These data indicate that although there is an attempt to plan, often a lack of discipline leads to budget overruns. When it comes to financial literacy, the majority of respondents believe that they understand basic financial terms such as savings, credit, interest and inflation, which was confirmed by 40.1% of respondents. However, there is also a significant number of respondents who believe that they do not have enough knowledge about managing

personal finances (10.7%), while 41.8% of respondents believe that a higher level of financial knowledge would help reduce impulse purchases.

Table 4. Respondents' views on financial planning, financial management and financial literacy

Question	I completely disagree	I disagree	I have no opinion	I agree	I completely agree
I regularly plan a monthly budget and stick to it.	14,6%	27,2%	21,5%	27,2%	9,5%
I often exceed the planned budget due to unplanned purchases.	13,4%	26,6%	16,4%	38%	7,6%
I use the minuses on the card to make an unplanned purchase	60%	22,2%	8,3%	7,6%	11,9%
I consider that I have sufficient knowledge about managing personal finances.	10,1%	10,7%	22,8%	41,8%	14,6%
Greater financial knowledge would help me reduce impulse buying.	10,8%	20,9%	27,9%	27,9%	12,6%
I understand basic financial concepts (savings, credit, interest, inflation, etc.)	9,6%	5,2%	5,8%	40,1%	39,3%

Source: creation of the author

The structure of the answer to the question "Are you getting information about ways to better manage personal finances?" it is shown in Table 5. Of the respondents, 39.9% are occasionally informed about finances, while 15.2% have never researched this topic. Given these data, there is obvious scope for improving financial education and providing training on personal finance management.

Table 5. Frequency of information on ways to better manage personal finances

Offered answer	N	%
Yes, I regularly follow financial topics.	15	9,5
I occasionally read/listen to educational content.	56	35,4
I rarely get informed.	63	39,9
I have never researched this topic	24	15,2

Source: creation of the author

The last survey question was "*Would you participate in personal finance/budget management training*?", where 55.1% of respondents gave the answer *Maybe*, 29.7% answered *Yes* and the remaining 15.2% said *No.*

This part of paper highlights several key limitations of the present study and offers recommendations for future research. The study employed a convenience sampling method, which limits the generalizability of the findings. The questionnaire was distributed via email and social media, resulting in a sample composed predominantly of younger and more digitally active individuals, with a strong overrepresentation of female respondents. This demographic imbalance may have influenced the results and restricts their applicability to the broader population. Also, this research relied on self-reported data, which can introduce biases such as selective memory, subjective interpretation, and social desirability bias—especially in questions related to personal finances, debt, and emotionally driven purchasing decisions.

Key recommendations for future research: Employ a more representative sample by utilizing random or stratified sampling methods to enhance the validity and generalizability of the findings; Incorporate qualitative research methods, such as in-depth interviews or focus groups, to gain a deeper understanding of the psychological and emotional factors influencing impulsive buying behaviour; Apply inferential statistical techniques to test hypotheses and identify statistically significant relationships between variables, thereby strengthening the analytical rigor of the study.

4. Conclusion

Based on the research results, the main hypothesis H_0: "*Impulsive consumer decisions result in unsuccessful management of personal finances and long-term financial instability*" - can be considered confirmed. A large number of respondents stated that impulsive purchases have a negative impact on their financial plans. Also, a significant

number of respondents admit that they often exceed the planned budget due to unplanned purchases, which indicates that impulsive spending makes it difficult to manage personal finances.

The results of the research confirm hypothesis H_1: Lack of budgeting and financial planning increases the tendency to make impulsive purchases and makes it difficult to manage personal finances in the long term, because most of the respondents stated that they often exceed the planned budget due to unplanned purchases. Also, most respondents admit that impulse purchases have a negative impact on their financial plans, which indicates that a lack of disciplined budgeting leads to greater financial problems. The second hypothesis H_2: A high level of financial literacy helps to reduce impulse purchases and enables better management of personal finances was confirmed. Although the majority of respondents believe that they understand basic financial terms (savings, credit, interest, inflation), the results show that there is a significant number of respondents (about 34%) who believe that they do not have sufficient knowledge about managing personal finances. These data suggest that a higher level of financial knowledge can significantly contribute to the reduction of impulse purchases and better financial management, which would enable long-term financial stability. The research results fully confirm hypothesis H_3: Big discounts and promotions encourage impulse buying, often to the detriment of rational management of personal finances, because the largest number of respondents stated that discounts and promotions mostly encourage their impulse buying. This indicates the strong influence of retailers' promotional strategies, which often encourage consumers to make hasty decisions, which can have negative consequences for their finances.

Hypothesis H_4: Greater availability of products due to digitization and online shopping opportunities increase the tendency to impulse buying and personal financial problems is also confirmed. The research showed that the respondent believes that the possibility of online shopping significantly increases the tendency to impulse purchases. This indicates that digitization and ease of access to products via the Internet may further exacerbate consumers' financial problems, making them more susceptible to unplanned spending.

Based on the research results, the following recommendations for future research and practice stand out:

- Education and training: It is necessary to invest in financial education, because a higher level of financial literacy can significantly reduce impulse buying and improve the management of personal finances.

-Budget management: Developing more discipline in planning and monitoring the budget could reduce the frequency of impulsive purchases and improve the long-term financial condition of the respondents.

-Regulation of marketing practices: Considering the impact of promotions and discounts on impulsive consumption, it is recommended to implement strategies that would reduce their negative impact, as well as promote responsible consumption.

In conclusion, the research confirmed that impulse buying has a significant impact on personal financial management, and that greater financial literacy, better budget control and reduction of marketing incentives can contribute to more stable and responsible management of personal finances.

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Law applicable to products liability

Asmira Bećiraj[1] and Lejla Bećiraj[2]

[1]Faculty of Law, University of Bihac, Bihac, Bosnia and Herzegovina
[2]Faculty of Law, University of Minnesota, USA

E-mail: asmira_beciraj@yahoo.com

Abstract. The ever-increasing development of technology and innovation on the one hand, and international trade on the other hand, has led to the need to establish rules that determine the applicable law for product liability. This paper analyzes the provisions of the Rome II Regulation as the basic regulation that regulates this subject in the European Union. After the presentation of the *ratione materiae, ratione temporis* and *ratione loci*, the answer to the question of which law is applicable for the non-contractual obligation caused by the damage caused by the product. The final considerations highlight the advantages and disadvantages of the provisions contained in the Rome II Regulation and suggest possible improvements.

1. General Overview

Over the course of six decades of European integration, the present-day EU has built—and continues to build—its legal system on the simultaneous harmonization and unification of public and private law provisions [1]. Until the entry into force of the Treaty establishing the European Community in its Amsterdam version on May 1, 1999 (hereinafter: TEC), private international law and international procedural law between the Member States of the European Community were not part of European law, as they were aligned through conventions signed and ratified by the Member States.

Since the adoption of legislation in the area of judicial cooperation in civil matters was (primarily) noticeably slow, efforts began to seek improvements to the legal system that would enhance the functional efficiency of EU law in this area as well [3]. To achieve the desired progress, it was necessary to accelerate the process of communitarization by granting even greater powers to the competent EU institutions [3]. With the Amsterdam Treaty, the Council, based on Article 61 of the EC Treaty, was granted powers to adopt various measures aimed at progressively achieving a common area of freedom, security, and justice—which is one of the goals of the EC—including measures to enable judicial cooperation in civil matters with cross-border implications, adopted to the extent necessary to ensure the functioning of the internal market [4]. After the Amsterdam Treaty, the integration process continued with the Treaty of Lisbon [5]. The EU institutions (European Parliament and the Council) are authorized to adopt measures (in particular) if they are necessary for the smooth functioning of the internal market, or if their objective is the establishment and functioning of the internal market.

For the exercise of the Union's competences, the institutions adopt regulations, directives, decisions, recommendations, and opinions (Article 288 [1] of the Treaty of Lisbon).
According to Article 288 [2], a regulation is defined as follows: "A regulation shall have general application. It shall be binding in its entirety and directly applicable in all Member States."

2. Rome II Regulation
Regulation (EC) no 864/2007 of the European Parliament and of the Council off 11 July 2007 on the law applicable to non-contractual obligations (Rome II) [7] entered into force in 2009. It represents an important step in the communitarization of private international law and is the most significant document in the field of determining the applicable law for non-contractual liability for damage, with the aim of maintaining and developing an area of freedom, security, and justice.

The subject of this paper is the set of provisions contained in the Rome II Regulation concerning the determination of the applicable law for product liability. Following an overview of the scope of application from all three aspects, as well as the concepts of damage and product, the paper analyzes the applicable law provisions and their fundamental principle: party autonomy.

3. Scope of Application
Within the scope of application of the Rome II Regulation, distinctions are made based on the subject matter it regulates (*ratione materiae*), the territorial scope where it applies (*ratione territorii*), and the temporal scope from which it applies (*ratione temporis*).

3.1. Ratione materiae
This Regulation shall apply, in situations involving a conflict of laws, to non-contractual obligations in civil and commercial matters. It shall not apply, in particular, to revenue, customs or administrative matters or to the liability of the State for acts and omissions in the exercise of State authority (acta iure imperii) (Article 1 [1]). Although at first glance the second sentence of Article 1 [1] of the Rome II Regulation may seem superfluous—since it specifically excludes tax, customs, and administrative matters, as well as state liability for acts and omissions in the exercise of state authority (*acta iure imperii*)—such a provision was nevertheless justifiably included due to the needs of common law countries.

The following shall be excluded from the scope of this Regulation: (a) non-contractual obligations arising out of family relationships and relationships deemed by the law applicable to such relationships to have comparable effects including maintenance obligations; (b) non-contractual obligations arising out of matrimonial property regimes, property regimes of relationships deemed by the law applicable to such relationships to have comparable effects to marriage, and wills and succession;

(c) non-contractual obligations arising under bills of exchange, cheques and promissory notes and other negotiable instruments to the extent that the obligations under such other negotiable instruments arise out of their negotiable character; (d) non-contractual obligations arising out of the law of companies and other bodies corporate or unincorporated regarding matters such as the creation, by registration or otherwise, legal capacity, internal organization or winding-up of companies and other bodies corporate or unincorporated, the personal liability of officers and members as such for the obligations of the company or body and the personal liability of auditors to a company or to its members in the statutory audits of accounting documents; (e) non-contractual obligations arising out of the relations between the settlors, trustees and beneficiaries of a trust created voluntarily; (f) non-contractual obligations arising out of nuclear damage; (g) non-contractual obligations arising out of violations of privacy and rights relating to personality, including defamation (Article 2).

3.2. Ratione territorii

This Regulation shall apply from 11 January 2009, except for Article 29, which shall apply from 11 July 2008. (Article 32 [2]). This Regulation shall apply to events giving rise to damage which occur after its entry into force (Article 31).

3.3. Ratione temporis

This Regulation shall be binding in its entirety and directly applicable in the Member States in accordance with the Treaty establishing the European Community (Article 32 [2]). For the purposes of this Regulation, 'Member State' shall mean any Member State other than Denmark (Article 1 [4]).

4. Product liability

The conflict-of-law rule in matters of product liability should meet the objectives of fairly spreading the risks inherent in a modern high-technology society, protecting consumers' health, stimulating innovation, securing undistorted competition and facilitating trade. Creation of a cascade system of connecting factors, together with a foreseeability clause, is a balanced solution in regard to these objectives. The first element to be taken into account is the law of the country in which the person sustaining the damage had his or her habitual residence when the damage occurred, if the product was marketed in that country. The other elements of the cascade are triggered if the product was not marketed in that country, without prejudice to Article 4 [2] and to the possibility of a manifestly closer connection to another country (Recital 20).

5. What is the product?

The Rome II Regulation does not provide an answer to the question of what constitutes a product; instead, it refers to the solutions contained in Council Directive 85/374/EEC of 25 July 1985 on the approximation of the laws, regulations and administrative provisions of the Member States concerning liability for defective products [9]. The producer shall be liable for damage caused by a defect in his product (Article 1). „For the purpose of this Directive 'product' means all movables, with the exception of primary agricultural products and game, even though incorporated into another

movable or into an immovable. 'Primary agricultural products' means the products of the soil, of stock-farming and of fisheries, excluding products which have undergone initial processing. 'Product' includes electricity“ (Article 2).

This concept of a product has been supplemented with agricultural products (Recital 8) by the provisions of the Directive 1999/34/EC of the European parliament and of the Council of 10 May 1999 amending Council Directive 85/374/EEC on the approximation of the laws, regulations and administrative provisions of the Member States concerning liability for defective products [10] and with digital products by the Directive (EU) 2024/2853 of the European Parliament and of the Council of 23 October 2024 on liability for defective products and repealing Council Directive 85/374/EEC [11].

6. Product liability

The Rome II Regulation, in Article 5, regulates the issue of product liability as follows: “Without prejudice to Article 4 [2], the law applicable to a non-contractual obligation arising out of damage caused by a product shall be: (a) the law of the country in which the person sustaining the damage had his or her habitual residence when the damage occurred, if the product was marketed in that country; or, failing that; (b) the law of the country in which the product was acquired, if the product was marketed in that country; or, failing that; (c) he law of the country in which the damage occurred, if the product was marketed in that country. However, the law applicable shall be the law of the country in which the person claimed to be liable is habitually resident if he or she could not reasonably foresee the marketing of the product, or a product of the same type, in the country the law of which is applicable under (a), (b) or (c). 2. Where it is clear from all the circumstances of the case that the tort/delict is manifestly more closely connected with a country other than that indicated in paragraph 1, the law of that other country shall apply. A manifestly closer connection with another country might be based in particular on a pre-existing relationship between the parties, such as a contract, that is closely connected with the tort/delict in question.“

7. Damage

As for what constitutes damage, the Rome II Regulation addresses this in Article 2. For the purposes of this Regulation, damage shall cover any consequence arising out of tort/delict, unjust enrichment, *negotiorum gestio* or *culpa in contrahendo* (Article 1 [1]). This Regulation shall apply also to non-contractual obligations that are likely to arise (Article 1 [2]). Any reference in this Regulation to: (a) an event giving rise to damage shall include events giving rise to damage that are likely to occur; and (b) damage shall include damage that is likely to occur.

8. Applicable law

Conflict-of-law rules are considered an essential part of European integration. In the area of applicable law for non-contractual obligations, the Rome II Regulation is based on party autonomy. Its core premise is that the parties have the ability to determine the applicable law by their own will. Today, party autonomy is perceived as a natural right

of the individual, which, in the contemporary multi-jurisdictional world, exists within the system of conflict-of-law rules but is subject to certain limitations [12].

When determining the applicable law for product liability, the Rome II Regulation is based on the so-called cascade system of connecting factors. In this system, party autonomy is given primary importance. If the parties have not agreed on the applicable law, then the solutions provided in Article 5 shall apply „Without prejudice to Article 4 [2], the law applicable to a non-contractual obligation arising out of damage caused by a product shall be: (a) the law of the country in which the person sustaining the damage had his or her habitual residence when the damage occurred, if the product was marketed in that country; or, failing that; (b) the law of the country in which the product was acquired, if the product was marketed in that country; or, failing that; (c) he law of the country in which the damage occurred, if the product was marketed in that country. However, the law applicable shall be the law of the country in which the person claimed to be liable is habitually resident if he or she could not reasonably foresee the marketing of the product, or a product of the same type, in the country the law of which is applicable under (a), (b) or (c). 2. Where it is clear from all the circumstances of the case that the tort/delict is manifestly more closely connected with a country other than that indicated in paragraph 1, the law of that other country shall apply. A manifestly closer connection with another country might be based in particular on a pre-existing relationship between the parties, such as a contract, that is closely connected with the tort/delict in question."

Accordingly, the second step in the so-called cascade system of connecting factors is contained in Article 5 [1], which includes the habitual residence of the person who suffered the damage, the place where the product was purchased, and the place where the damage occurred—all under the condition that the product was marketed in that country. This is subject to the provision that a stronger connection does not exist as stated in Article 5 [2]; if it is clear from all the circumstances of the case that the wrongful act is manifestly more closely connected with a country other than that referred to in paragraph 1, the law of that other country shall apply. Such a connection may be based, for example, on a contract.

9. Freedom of choice

The significance of party autonomy is clearly reflected in the Rome II Regulation, where Recital 31 states: To respect the principle of party autonomy and to enhance legal certainty, the parties should be allowed to make a choice as to the law applicable to a non-contractual obligation. This choice should be expressed or demonstrated with reasonable certainty by the circumstances of the case. Where establishing the existence of the agreement, the court has to respect the intentions of the parties. Protection should be given to weaker parties by imposing certain conditions on the choice.

The provisions on which the Rome II Regulation is based are contained in Article 14, and read as follows: „The parties may agree to submit non-contractual obligations to the law of their choice: (a) by an agreement entered into after the event giving rise to the damage occurred, or (b) where all the parties are pursuing a commercial activity, also by an agreement freely negotiated before the event giving rise to the damage occurred. The choice shall be expressed or demonstrated with reasonable certainty by

the circumstances of the case and shall not prejudice the rights of third parties 14 [1]. Where all the elements relevant to the situation at the time when the event giving rise to the damage occurs are located in a country other than the country whose law has been chosen, the choice of the parties shall not prejudice the application of provisions of the law of that other country which cannot be derogated from by agreement 14 [2]. Where all the elements relevant to the situation at the time when the event giving rise to the damage occurs are located in one or more of the Member States, the parties' choice of the law applicable other than that of a Member State shall not prejudice the application of provisions of Community law, where appropriate as implemented in the Member State of the forum, which cannot be derogated from by agreement 14 [3].

10. Conclusion

The Rome II Regulation was adopted with the aim of ensuring legal certainty, predictability, and flexibility in legal relationships. Its fundamental principle is the possibility of choosing the applicable law in non-contractual relationships, including in the determination of the applicable law for product liability. It is precisely through the free choice of applicable law that parties are enabled to select the legal system that best suits their needs—naturally, under certain conditions. These provisions thus fulfill the above-mentioned objective of the Rome II Regulation.

In addition to party autonomy, one of the Regulation's advantages is that it is adapted to technological developments through its definition of a product. The provisions of the Rome II Regulation also clearly show a commitment to protecting the injured party. Based on the rules contained in the Regulation, it is evident that the habitual residence of the injured party will most often be applied, which is why we can say that the Rome II Regulation favors the protection of the injured person.

Furthermore, although the cascade system is inherently complex, its application yields positive results, as reflected in the clearly indicated order of connecting factors used by the Rome II Regulation.

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Human Trafficking

Merisa Nesimović and Nikola Findrik

Faculty of Law, University of Bihać, Bihać, Bosnia and Herzegovina

E-mail: merisa.nesimovic07@gmail.com

Abstract. In the article, the authors analyze the problem of human trafficking as one of the most serious forms of human rights violations and transnational crime. The focus of the research is on the legal framework for combating human trafficking, including international conventions, regional instruments and domestic legislation of Bosnia and Herzegovina. Special attention is given to the identification and protection of victims, prevention mechanisms and the sanctioning of perpetrators, along with the analysis of challenges in their practical application. The key elements of this crime are analyzed, including forms of exploitation, methods of recruiting victims and factors that contribute to its spread. Also, the role of institutions and non-governmental organizations in the fight against human trafficking and providing support to victims is investigated, as well as the application of international standards in domestic judicial practice. The authors consider the effectiveness of existing solutions and propose possible improvements in the legislative and institutional framework in the direction of strengthening the legal protection of victims, improving prevention and increasing the efficiency of court proceedings. The research uses normative, analytical and comparative methods, with the use of relevant sources and data on practices in the fight against human trafficking.
Keywords: Human trafficking, violation of human rights, transnational crime, identification and protection of victims, Bosnia and Herzegovina, recruitment of victims.

1. Introduction

Human trafficking is one of the most serious forms of modern slavery and one of the most serious violations of fundamental human rights. This complex and multidimensional phenomenon is also a form of transnational organized crime that has profound consequences for victims, communities and society as a whole. Although the global community has been fighting this problem for decades through international conventions and cooperation between states, human trafficking is still present in almost all parts of the world, including Bosnia and Herzegovina. Human trafficking is a global problem, which is present in all cultures and societies of the modern world. There is no country in the modern world that is immune to this problem. Human trafficking represents the negation of the principle of humanity and denotes the most severe form

of human degradation. [8] According to the definition, human trafficking represents the begging, transportation, transfer, hiding of people by force, deception or fraud, all with the aim of exploiting them for profit.

The phenomenon of "human trafficking" would not be so dangerous if it did not change quickly and take on new forms. The spread of this problem also contributed to the fact that the forms of exploitation of people were not limited to sexual exploitation, that is, more intensively to forced prostitution and forced labor. In recent times, it takes on a new form in the form of harvesting human organs, exploiting people in pornography and other forms of the growing "sex industry" and through other forms of slave labor. The worrying trend is that the victims are mostly children (girls), and increasingly also men-boys, younger and younger - which makes this problem more complex and problematic in relation to the violation of human rights and basic freedoms and the provision of adequate protection, first of all, to children and minors and other marginalized groups of the population / foreigners, refugees, immigrants, minorities and others. [1] At the core of this phenomenon lies exploitation – whether it involves forced labor, sexual exploitation, forced begging, or other forms of abuse – with the most vulnerable groups often being women, children, and migrants. Victims are most commonly recruited through deception, coercion, or abuse of a position of vulnerability, and the complexity and hidden nature of this issue further hinder their identification and the provision of adequate assistance.

The phenomenon of human trafficking has been present in Bosnia and Herzegovina for more than two decades, with some indicators pointing to practices of exploiting people for purposes such as prostitution, forced begging, and other forms of exploitation that emerged immediately after the end of the armed conflict. With the beginning of this millennium, the first international treaties and legal instruments were adopted under the auspices of the United Nations, the Council of Europe, the European Union, and others, aiming to harmonize efforts at the international level to criminalize human trafficking and establish a set of standards for mutual cooperation between states, particularly in terms of protecting victims of human trafficking, in order to bring this phenomenon under effective control. As a member of most of these organizations, Bosnia and Herzegovina criminalized human trafficking in its domestic legislation already in 2003 as part of criminal law reform. [2]

This article analyzes the legal framework and institutional practices in Bosnia and Herzegovina in combating human trafficking, through the lens of international standards and domestic legislation. Special emphasis is placed on the protection of victims, mechanisms for prevention, and the prosecution and sanctioning of perpetrators, as well as the challenges faced by competent institutions and non-governmental organizations in practice. The aim of the research is to identify existing shortcomings and offer recommendations for improving the system in order to ensure a more comprehensive, effective, and human rights-oriented response to this form of crime.

2. Definition and forms of human trafficking

The most comprehensive and widely accepted definition of human trafficking is provided in Article 3 of the Palermo Protocol to the United Nations Convention against Transnational Organized Crime (2000). It defines human trafficking as: "the recruitment, transportation, transfer, harbouring or receipt of persons, by means of the threat or use of force or other forms of coercion, of abduction, of fraud, of deception, of the abuse of power or of a position of vulnerability or of the giving or receiving of payments or benefits to achieve the consent of a person having control over another person, for the purpose of exploitation." Exploitation shall include, at a minimum, the exploitation of the prostitution of others or other forms of sexual exploitation, forced labour or services, slavery or practices similar to slavery, servitude or the removal of organs. State parties are obligated to adopt legislative and other measures to criminalize this act, accompanied by appropriate sanctions. [3][15] The Protocol emphasizes the duty of states to provide victims of trafficking with protection, security, physical and psychological assistance, as well as access to justice and reparations.

The term human trafficking is often mistakenly interchanged with concepts such as human smuggling, migration, and prostitution, as these phenomena may, but do not necessarily, result in human trafficking. Human trafficking does not only affect the individual who is subjected to the criminal act, but also has adverse effects on the social and economic aspects of modern society—an assessment shared by numerous authors who study this phenomenon. In the literature, various criteria can be found for classifying forms of human trafficking, including: the degree of social danger, the geographic level of execution, the victim's relationship to their position, the bio-physiological characteristics of the victim, and the form of exploitation involved. [4] Within the broader scope of human trafficking, child trafficking stands out as one of the most brutal and unscrupulous forms of violence against children. In the context of our region, it is an indisputable fact that human trafficking—and especially child trafficking—is a particularly acute problem. In this regard, Bosnia and Herzegovina appears simultaneously as a country of origin, transit, and destination.

There are various forms of human trafficking. The most well-known form involves different types of sexual exploitation, including forcing individuals to engage in commercial sexual acts such as prostitution or the production of pornography. In addition to sexual exploitation, forced labor is also highly prevalent worldwide. This occurs when individuals are compelled to perform labor or provide services against their will through the use of force, fraud, or coercion. In 2016, the International Labour Organization estimated that 24.9 million people globally were subjected to forced labor. Certain risk factors increase the likelihood that an individual will become a victim of labor trafficking, such as unstable immigration status, poverty, lack of social support, or having experienced specific types of trauma. [14]

The United Nations estimates that approximately four million people fall victim to human trafficking each year, and that this illegal "industry" generates up to ten billion

dollars annually, making it the third-largest illicit industry in the world—following drug and arms trafficking. In the Balkans, human trafficking existed prior to recent decades, but its expansion primarily occurred as a consequence of the war and the dissolution of the former Socialist Federal Republic of Yugoslavia. These events were accompanied by widespread destruction, displacement, and uncontrolled population migration, along with the presence of numerous domestic and foreign military forces. War and poverty significantly contributed to the increased visibility and prevalence of this phenomenon in our society. [5] According to data from the International Labour Organization and the United Nations, there are currently around 49.6 million people worldwide living in modern slavery, including 12 million children. Women and girls make up 54% of the victims, while men and boys account for the remaining 46%. Sexual exploitation is the most common form of human trafficking, especially in North America, whereas forced labor is dominant in Asia and Africa. In 2023, the EU registered 10,793 victims of human trafficking, representing a 6.9% increase compared to 2022. The number of suspected traffickers rose by 5%, while the number of convicted traffickers increased by 10.1% during the same period. The UN reports that the number of human trafficking victims grew by 25% between 2019 and 2022, attributing this to conflicts, climate disasters, and global crises. Victims of forced labor are most often compelled to work in agriculture, various domestic chores, factory jobs, nightclubs, and more. [11][12][13] As with any other form of crime, it is suggested that official statistics do not reflect the true scale of the problem, due to misinterpretations and shortcomings in identification mechanisms for victims of human trafficking—especially victims of new forms of trafficking—as well as other reasons commonly associated with the so-called “dark figure” of crime.

A specific and widespread form of human trafficking is forced begging. Forced begging represents a particular type of human trafficking where individuals, often children, are coerced into begging through the use of force, threats, or deception. This practice is recognized as a form of exploitation within international legal instruments, including the Palermo Protocol. [6] In Bosnia and Herzegovina, the problem of begging is particularly pronounced, primarily due to poverty in society, but also because of the unstable socio-legal system in general. Child begging is a frequent phenomenon, making children on the streets an almost common sight in Bosnian-Herzegovinian cities. Forced begging represents one of the most obvious, yet often neglected forms of human trafficking, where victims are forced to beg and must hand over all collected money to their exploiters. This practice involves a wide range of victims, including children, persons with disabilities, and marginalized groups, and occurs in various forms worldwide. Forced begging is defined as a form of forced labor or service, where individuals are compelled to beg through physical or psychological coercion, deception, or exploitation of vulnerability. According to the Council of Europe Convention on Action against Trafficking in Human Beings, this practice is considered a form of exploitation and is included within the broader concept of human trafficking. The

European Union, through the Brussels Declaration, also recognizes forced begging, especially of children, as a form of human trafficking. Victims of forced begging are often subjected to physical violence, psychological manipulation, and threats. Children are particularly vulnerable as they are often under the control of family members or criminal groups who force them to beg. In many cases, children are forced to beg on the streets, often under threats of violence or punishment if daily quotas are not met. Forced begging is frequently linked to organized criminal groups that use this practice as a source of income. Victims are often compelled to hand over all the money they collect, without any possibility of keeping earnings. Persons with disabilities are especially vulnerable to forced begging. In some cases, traffickers deliberately inflict injuries to increase passersby's sympathy and thus raise more money. Identifying victims of forced begging can be challenging, as begging is often perceived as an individual activity. However, signs such as the presence of supervisors, signs of physical abuse, or obvious dependency may indicate forced begging. In Bosnia and Herzegovina, forced begging, especially of children, represents a significant problem. According to 2021 data, out of 57 potential victims of human trafficking, 54 were children, mostly exploited through begging. Experts warn that the actual number of victims may be much higher due to underreporting and the invisibility of these cases. [7] Forced begging is a serious form of human trafficking that requires a comprehensive approach, including legal, social, and educational measures. It demands special attention from legislative bodies, law enforcement agencies, and society as a whole. Only through coordinated efforts at the local, national, and international levels can this practice be effectively combated and the most vulnerable members of society protected. There is a great need to harmonize national laws with international standards to more effectively prosecute cases of forced begging. The exchange of information and joint actions between countries are also crucial in dismantling human trafficking networks. In this form of human trafficking, particular attention must be given to ensuring adequate protection, rehabilitation, and reintegration of victims into society.

Human trafficking represents one of the most complex and dangerous forms of modern slavery, whose definition encompasses a range of elements—from recruitment and transportation to exploitation through force, threats, deception, or abuse of vulnerability. In contemporary international and domestic law, it is recognized not only as a criminal offense but also as a serious violation of fundamental human rights. Understanding the basic elements of this phenomenon is crucial for effectively identifying and combating human trafficking, especially in the context of protecting the most vulnerable population groups—women, children, migrants, and persons with disabilities. An analysis of the main forms of human trafficking—sexual exploitation, forced labor, and forced begging—reveals that victims are systematically exploited in various contexts, with control methods that are sophisticated and often difficult to detect. Although these forms differ in methods of execution and objectives of exploitation, they share a common mechanism of subjugating the victim and violating

their dignity. This chapter lays the foundation for further consideration of the legal and institutional response to the problem of human trafficking, with a particular focus on international standards and the national legal framework in Bosnia and Herzegovina.

3. Domestic and international legal framework in the fight against human trafficking

There are numerous sources of international law that regulate prevention, criminalization, victim protection measures, cooperation mechanisms, and other issues aimed at combating human trafficking. These primarily include international conventions, declarations, resolutions, and other international documents that serve as legal sources in this field. The Palermo Protocol – formally known as the Protocol to Prevent, Suppress and Punish Trafficking in Persons, Especially Women and Children – is a key international instrument in the fight against human trafficking. It was adopted in 2000 as a supplement to the United Nations Convention against Transnational Organized Crime and entered into force on December 25, 2003. To date, it has been ratified by 180 countries, including Bosnia and Herzegovina. The Protocol has three main objectives: preventing and combating human trafficking, protecting and assisting victims of trafficking, and promoting cooperation among states to achieve these goals. States that have ratified the Protocol are obliged to criminalize human trafficking within their national legislation, establish measures for the protection and assistance of victims, including physical, psychological, and social recovery, provide victims with temporary or permanent residence permits for humanitarian reasons, conduct awareness campaigns and education to prevent trafficking, and cooperate with other countries in identifying and prosecuting offenders. Although the Palermo Protocol laid the foundation for the international fight against human trafficking, it faces certain criticisms. Critics argue that the Protocol places too much emphasis on criminal prosecution while neglecting the socio-economic causes of human trafficking, such as poverty and inequality. The term "exploitation" is not precisely defined, which can lead to varying interpretations and applications in practice. Bosnia and Herzegovina has ratified the Palermo Protocol and incorporated its provisions into national legislation. Article 186 of the Criminal Code of Bosnia and Herzegovina criminalizes international human trafficking, prescribing prison sentences of at least five years, and in cases where the victim is a child, the sentence is at least ten years. The Palermo Protocol represents a crucial international instrument in combating human trafficking, setting standards for prevention, victim protection, and criminal prosecution of perpetrators. While it has made significant progress in harmonizing legislation and raising awareness, challenges in implementation remain, especially regarding the protection of victims' rights and addressing the root causes of human trafficking.

Additional international documents prohibiting human trafficking include the Convention on the Elimination of All Forms of Discrimination Against Women (CEDAW)

and the Convention on the Rights of the Child. CEDAW explicitly prohibits the exploitation of women through trafficking and prostitution, emphasizing the need for gender-sensitive legislation. The Convention on the Rights of the Child recognizes that children are a particularly vulnerable category and require specific legal protection. It prohibits trafficking in children, sexual exploitation, forced labor, and unlawful adoption for profit. Children are protected regardless of race, gender, origin, or parental status. Children's rights are not merely moral norms but are imposed as international obligations. To enhance the fight against these phenomena, the Convention also recommends international cooperation, especially in combating cross-border cases. Trafficking in children and sexual abuse are prohibited as ius cogens norms — norms of the highest international law. National governments are obliged to align their legislation with the provisions of this Convention and its accompanying protocols. This further ensures prevention, victim protection, and prosecution of perpetrators. [5]

Significant efforts in the fight against human trafficking have also been made by regional organizations, primarily the Council of Europe, as well as supranational organizations, chiefly the European Union. The European Convention on Human Rights of 1950, in Article 4, prohibits slavery and forced labor as absolute human rights without exceptions, even in a state of emergency. Although it does not explicitly mention human trafficking, it is considered a form of modern slavery due to the exploitation of victims treated as commodities. The case law of the European Court of Human Rights (e.g., the Rantsev, Siliadin, Chowdury cases) recognizes various forms of exploitation as violations of Article 4. The Council of Europe Convention on Action against Trafficking in Human Beings (2007) focuses on victim protection, crime prevention, reducing demand for victims' services, and international cooperation. Special emphasis is placed on the identification of victims and their protection from criminal prosecution as illegal migrants. It imposes obligations on states, including the criminalization of human trafficking, use of false documents, as well as punishment for attempts and complicity. The Convention allows prosecution even without the victim's testimony, recognizes internal human trafficking, and prescribes victims' rights to assistance and legal protection. Bosnia and Herzegovina is a party to this Convention, which takes precedence over domestic laws. Additionally, it has acceded to the Lanzarote Convention on the Protection of Children against Sexual Abuse, which provides for the strict criminalization of child prostitution, pornography, and sexual tourism.

The primary instruments for combating human trafficking in Bosnia and Herzegovina are domestic criminal laws, namely the Criminal Code of Bosnia and Herzegovina (CC BiH), the Criminal Code of the Federation of Bosnia and Herzegovina (CC FBiH), the Criminal Code of the Republika Srpska (CC RS), and the Criminal Code of the Brčko District of Bosnia and Herzegovina (CC BD BiH). Human trafficking is criminalized in all these laws, together with related offenses such as slavery and procuring prostitution, thereby creating a broad framework for prosecution. However, due to similarities and overlaps in the elements of these offenses, legal ambiguities arise

in their application. Criminal offenses with an international element are regulated by the CC BiH, while internal forms (within BiH) are governed by the entity laws and the Brčko District law.

Human trafficking is a complex criminal offense composed of three elements: the act, the means (method), and the purpose (goal), all of which must be cumulatively fulfilled for the offense to exist. An exception applies to cases involving minor victims, where the existence of the act and the purpose of exploitation are sufficient, regardless of the means used. The Council of Ministers of BiH adopted the Strategy to Combat Human Trafficking for the period 2024–2027. The Strategy aims to strengthen the legal and institutional framework, ensure effective prevention, protect victims, and prosecute perpetrators, in alignment with international standards. The Strategy focuses on improving legislation and institutional capacities, educating and training relevant actors, enhancing victim identification and protection, and strengthening cooperation between state institutions and the non-governmental sector. [9]

Human trafficking represents a serious violation of human rights that requires a coordinated response both at the international and domestic levels. International legal instruments, such as the European Convention on Human Rights and the Council of Europe Convention on Action against Trafficking in Human Beings, set high standards for victim protection, prevention, and criminal prosecution, and Bosnia and Herzegovina has committed to their implementation. These instruments define human trafficking as a modern form of slavery and particularly emphasize the obligation of states to protect vulnerable groups, especially minors. At the domestic level, Bosnia and Herzegovina has established a legislative framework through four criminal codes that criminalize human trafficking and related offenses. Effective combat against human trafficking requires consistent application of the law, improved coordination between levels of government, continuous alignment of domestic legislation with international standards, and strong protection and support for victims. Only through such measures is it possible to address the complexity of this crime and ensure effective suppression of one of the most serious forms of exploitation in modern society.

4. Victim identification and protection mechanisms

Identification of victims of human trafficking represents a crucial step in combating this serious violation of human rights. The identification of human trafficking victims in Bosnia and Herzegovina faces numerous challenges, including the complexity of cases and a lack of adequate training among professionals. According to the Council of Europe, victim identification should be based on clear indicators, including physical and psychological signs of abuse, restriction of freedom of movement, forced labor, and other forms of exploitation. It is also recommended that victims be granted a “reflection and recovery period” during which they will not be deported and will receive necessary assistance. The Council of Europe has developed a Resource Package for providing

information and legal assistance to victims, as well as improving training for combating human trafficking. This package includes manuals and brochures intended for legal professionals and victims, aimed at enhancing victim identification and support. [17]Protection of human trafficking victims encompasses ensuring safe accommodation, medical and psychological assistance, legal support, and social reintegration. In Bosnia and Herzegovina, non-governmental organizations play a key role in delivering these services, often in cooperation with state institutions. Projects such as "Strengthening Access to Justice for Victims of Human Trafficking" contribute to enhancing institutional capacities to provide adequate victim support. [16] Prevention of human trafficking involves education, awareness-raising, and strengthening institutional capacities. The prosecution of human trafficking offenders in Bosnia and Herzegovina is regulated by the Criminal Code; however, law enforcement faces challenges such as lack of resources and insufficient institutional coordination. According to various reports, the number of prosecutions and convictions for human trafficking remains low, and perpetrators often receive sentences below the statutory minimum. The Council of Europe has also developed guidelines on protecting the privacy and personal data of human trafficking victims, which have been implemented in Bosnia and Herzegovina. These guidelines aim to ensure that victims' identities remain protected to prevent further victimization. Combating human trafficking requires a coordinated and comprehensive approach that includes victim identification, protection and support, prevention, and effective prosecution of perpetrators.

When discussing forms of protection for victims of human trafficking, it is important to mention that victims enjoy general protection in accordance with the Rules on the Protection of Victims and Witnesses who are Victims of Human Trafficking and Citizens of Bosnia and Herzegovina (2007) and the Regulation on the Protection of Foreign Victims of Human Trafficking (2016). All victims involved in criminal proceedings related to human trafficking, whether as witnesses or injured parties, have the right to legal representation. However, since the injured party is not a party to the proceedings, the actions the legal representative can undertake are limited to providing legal advice regarding testifying as a witness and assisting with submitting civil claims. The legal and institutional framework in Bosnia and Herzegovina provides for additional forms of witness protection in criminal proceedings involving victims of human trafficking. These include testimony via video-link from a special courtroom, support from witness support departments through the granting of protected witness status. However, such protections are granted in a limited number of cases, whereas the institute of excluding the public from court sessions is applied somewhat more frequently. [2]When discussing the prevention of human trafficking, there are primary, secondary, and tertiary prevention measures. Primary prevention aims to strengthen protection systems that should operate effectively in high-risk circumstances, establish control mechanisms, and prevent the emergence of risk factors. Within these measures, it is essential to develop the capacities of competent institutions to effectively recognize

risky situations and vulnerable groups. Secondary prevention targets already identified vulnerable individuals, families, and high-risk environments. It focuses on determining the prevalence of risk factors for child trafficking within these identified groups and communities and on educating relevant professionals to recognize risk factors and appropriately address such situations. Tertiary prevention involves treatment provided after a person has already been victimized. The goal of treatment is to prevent the recurrence of abuse and to mitigate the consequences of violence. [10] Victims receive psychosocial and any other necessary forms of assistance appropriate to their circumstances. Numerous institutions can provide assistance and support in the prevention, identification, and protection of victims of human trafficking. Educational institutions can aid in early detection, data collection, education, and providing support to children who are victims of human trafficking. The social protection system, in terms of prevention, aims to cooperate with educational and healthcare institutions to collect data, monitor families, identify forms, intensity, and consequences of abuse, plan protection interventions and treatments, implement social protection measures, and apply legal protection measures within the jurisdiction of guardianship authorities. The healthcare system's role in prevention involves identifying forms and intensity of abuse, assessing health status, and determining risk factors from a health perspective. Criminal justice protection, specifically physical protection provided by the police, aims to detect and collect evidence about the case and perpetrator, initiate criminal proceedings, conduct investigations, and prosecute the offender for the criminal act.

Political instability, along with the country's difficult social and economic situation, continues to create an environment that facilitates human trafficking. Additionally, Bosnia and Herzegovina remains a post-conflict country in transition, with developing democracy and fragile institutions. In such an environment, numerous factors known as "push and pull factors" that attract and promote human trafficking are identifiable. These include the status of women, the status of children, the status of persons with disabilities, the status of national minorities—especially the Roma community—widespread corruption and its links to trafficking, poor economic conditions and high unemployment, and underdeveloped mechanisms for protecting victims' rights. While the number of identified foreign victims is steadily decreasing, the number of Bosnian citizens identified as victims of human trafficking within Bosnia and Herzegovina's borders is continuously increasing. Bosnia and Herzegovina has become a country of origin, transit, and destination for victims of human trafficking. Insufficient protection of victims' rights is also one of the factors that contributes to the survival of human trafficking in Bosnia and Herzegovina.

The fight against human trafficking represents one of the most complex challenges in the field of human rights protection in modern society. This phenomenon infringes upon fundamental human rights, including the right to freedom, dignity, personal security, and protection from exploitation. In this context, mechanisms for the identification, protection, and prevention of human trafficking victims constitute key

components of an effective state and societal response to this problem. Identification of victims is the first and indispensable step in the protection system. Without precise, timely, and sensitive identification, victims remain beyond the reach of assistance and justice. To achieve this, continuous professional development is necessary for those who come into contact with potential victims — police officers, social workers, healthcare professionals, and educators. Protection and support for victims of human trafficking must be comprehensive and long-term. This includes immediate physical safety, health and psychological assistance, access to legal protection, and, importantly, long-term reintegration into society. Non-governmental organizations, in cooperation with institutions, play a crucial role in this process, but without adequate state support and systemic funding, protection remains fragmented and insufficiently accessible. Prevention of human trafficking, on the other hand, requires long-term strategic measures. Public education, especially targeting youth, empowerment of vulnerable groups, raising awareness about the forms of human trafficking (sexual exploitation, forced labor, begging, forced marriage, etc.), and strengthening the capacities of relevant institutions must be priorities of any serious prevention policy. Media and the educational system play a special role in this, as do digital platforms, which can serve both as tools for information dissemination and as means of exploitation.

Ultimately, an effective fight against human trafficking is not possible without clearly defined political will, inter-institutional cooperation, and consistent law enforcement. Although the normative framework in Bosnia and Herzegovina is aligned with international standards, its implementation still faces obstacles — from a lack of resources, inconsistent judicial practices, to weak inter-entity coordination. Therefore, it is essential that the state continuously invests in the development of the protection system, strengthens prevention mechanisms, and provides education for professionals, while also ensuring active participation of civil society and international partners. Institutions such as the Ministry of Security of BiH, the Ministry of Human Rights and Refugees, and judicial authorities, together with non-governmental organizations, play a key role in combating human trafficking. Cooperation among these actors is vital for effective identification, protection of victims, and prosecution of perpetrators. Only in this way can it be ensured that every victim is recognized, protected, and restored to a life worthy of human dignity — because human trafficking is not only a criminal offense but also a profound violation of human dignity and freedom.

5. Concluding remarks

Human trafficking represents one of the most serious and complex forms of modern slavery, which not only violates fundamental human rights but also severely endangers the dignity, security, and freedom of victims. The global and multidimensional nature of this phenomenon requires a coordinated and systemic response at all levels of society, particularly an effective synergy between legislative frameworks, state institutions, civil

society, and the international community. An analysis of Bosnia and Herzegovina's legal and institutional framework, in light of international standards, reveals significant progress in normative regulation and formal mechanisms for combating human trafficking, but also numerous challenges that remain in practice. Although Bosnia and Herzegovina has recognized this issue as a priority through the ratification of relevant international conventions and the incorporation of their provisions into domestic legislation, the reality on the ground shows that existing capacities for victim identification, protection, and rehabilitation are still insufficient. The complexity of human trafficking, especially through forced begging, sexual exploitation, and forced labor, requires the development of integrated and multidisciplinary approaches, with special attention to vulnerable groups such as children, women, migrants, and persons with disabilities. In this regard, it is crucial that legislation be further improved by clearly defining the responsibilities of all actors, tightening sanctions for perpetrators, and ensuring specific mechanisms for the legal and social protection of victims. It is also recommended to establish more efficient procedures for identification and reporting, as well as better coordination between police, judicial, and social institutions, including non-governmental organizations that are often the first to provide assistance to victims. NGOs and civil society have an indispensable role in raising awareness, educating the public, and providing direct support to victims. Therefore, it is necessary to ensure their sustainable operation through adequate funding, institutional support, and inclusion in policymaking at the national level. Additionally, continuous education and training of professionals in the fields of law, social protection, and healthcare are of particular importance for timely recognition and assistance to victims of human trafficking. Society as a whole needs to be sensitized to the scope and consequences of this phenomenon, while strengthening a culture of human rights and tolerance. An effective fight against human trafficking is not possible without a change in attitudes and the recognition of this problem as a priority at every level.

The domestic and international legal framework in the fight against human trafficking constitutes a complex and multi-layered system of norms and measures aimed at prevention, victim protection, and prosecution of perpetrators of this serious criminal offense. The Palermo Protocol, as a key international instrument, established fundamental standards that states, including Bosnia and Herzegovina, are obliged to implement into their legislation. Alongside it, other important international documents—such as the Convention on the Elimination of All Forms of Discrimination against Women, the Convention on the Rights of the Child, and instruments of the Council of Europe and the European Union—further strengthen legal protection and international cooperation. At the domestic level, Bosnia and Herzegovina has established a legal framework through its criminal laws that enables the prosecution of human trafficking; however, challenges remain in the application and coordination across various levels of government. The adoption of the Strategy to Combat Human Trafficking for the period 2024–2027 demonstrates the country's commitment to

improving this legal and institutional framework. Nevertheless, effective combat against human trafficking requires not only legislative measures but also active cooperation, education, and adequate protection of victims—especially the most vulnerable groups such as children and women. Given the complexity and gravity of this form of exploitation, ongoing harmonization of domestic legislation with international standards, along with strengthening implementation and oversight, are essential for creating an effective system that fully addresses the challenges of human trafficking in modern society.

Police officers, social welfare workers, healthcare professionals, judicial officials, and employees of non-governmental organizations must be trained to recognize indicators of human trafficking and to make every effort to protect the victim, their rights, and dignity. An important aspect of victim identification is the application of a multidisciplinary approach, which involves establishing and strengthening coordination between institutions, civil society organizations, and international partners. This cooperation should be formalized through protocols and memoranda to ensure timely information exchange, victim safety, and adequate service provision. It is also crucial to ensure that victims of human trafficking are actively involved in the processes concerning their protection and reintegration, giving them the opportunity to express their needs and preferences. Providing support through individualized protection and reintegration plans increases the chances of their successful return to society while reducing the risk of re-victimization. Considering that many victims—especially those from vulnerable groups such as children, women, and members of national minorities—are exposed to additional risks, it is necessary to implement special protective measures that include psychological support, security measures, and access to education and employment. For more effective prevention and protection, Bosnia and Herzegovina should intensify efforts to establish a unified database on victims of human trafficking, which would enable better record-keeping, monitoring, and evaluation of protection measures. At the same time, the data would serve to plan strategic policies and allocate resources where they are most needed. The importance of involving the wider public in the fight against human trafficking must not be overlooked. Awareness-raising campaigns targeting different social groups, as well as the promotion of safe reporting channels for suspicions of trafficking, are essential. Helplines, applications, and other digital platforms can serve as modern tools in the process of identifying and protecting victims. In conclusion, the fight against human trafficking requires the continuous commitment of the state and society to stop this serious form of human rights violation through effective identification mechanisms, timely and adequate victim protection, and strong preventive measures—thus enabling every person to live freely and with dignity.

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The impact of international accounting standards on the quality of financial reporting

Irnesa Kujundžić and Dijana Vuković

Faculty of Economics at the University of Bihać, Bihać, Bosnia and Herzegovina

E-mail: irnesa.kujundzic@unbi.ba

Abstract. Financial reporting, as the foundation of the accounting function, plays a key role in modern business. Precise and timely financial reporting provides the basis for business analysis, making strategic decisions and gaining the trust of investors, creditors and other interested parties. In this context, international accounting standards (IAS) and international financial reporting standards (IFRS) play a significant role in harmonizing accounting practice on a global level. The aim of this paper is to analyze the impact of the application of IAS/IFRS on the quality of financial reporting, with a special focus on the transparency, accuracy and timeliness of financial data. The work includes a review of relevant literature and a comparative analysis of regulatory frameworks. The research results indicate that the implementation of IAS/IFRS significantly improves the quality of financial reporting and increases investor confidence.

1.Introduction

Financial reporting represents the basis for making economic decisions, as it enables interested parties to assess the financial condition and performance of the company. The application of international accounting standards (IAS) and international financial reporting standards plays an important role here because they contribute to the identification and resolution of financial reporting problems. However, there is still a debate about how much their application contributes to increasing the transparency, accuracy and comparability of financial information. The aim of this paper is to analyze the impact of IAS/IFRS on the quality of financial reporting, investigating whether their implementation improves the reliability and usefulness of information for investors and other interested parties. The basic research hypothesis of the paper is that the adoption of IAS/IFRS positively affects the quality of financial reporting, reducing opportunities for accounting manipulations and increasing the comparability of financial data at the international level.

2. Theoretical framework of the study

2.1 Development of International Accounting Standards (IAS) and Financial Reporting Standards (IFRS)

Legal provisions in the field of accounting prescribe the obligation for companies to apply appropriate accounting standards (international and/or national) competent for recognition and measurement and publication of individual elements of financial statements. A standard is a document determined by consensus adopted by a recognized body and in which rules, guidelines or characteristics for activities or their results are determined for general and repeated use in order to achieve an optimal level of organization in a certain area of activity. An international standard is a standard adopted by an international organization (international body) for standardization and which is available to the public (Accounting and Auditing Act of Bosnia and Herzegovina).

The year 1973 and the establishment of the International Accounting Standards Committee (IASC - International Accounting Standards Committee) was crucial for the development of International Accounting Standards. One of the most significant roles of this Committee was the issuance of the International Accounting Standards (IAS), which were published for the first time in 1975. This was followed by the publication of a whole series of IAS, which were changed, refined and supplemented. In the further development of these standards, a turning point occurred in 2001, when the Committee changed its name to the International Accounting Standards Board (IASB).

International Accounting Standards – IAS represent accounting standards introduced to achieve transparency and uniformity of financial statements of any economic entity, regardless of the activity it engages in and the country in which it operates (Vuković, Džanić, Kujundžić, 2024, p.80).

International Financial Reporting Standards-IFRS is developed and adopted by the International Accounting Standards Board (IASB). The body that interprets IFRS is the International Financial Reporting Interpretations Committee (IFRIC). The IFRIC's role is to provide timely guidance on newly identified financial reporting issues not specifically addressed by IASB standards or issues for which inadequate or conflicting explanations have been created, or are likely to arise. In this way, it promotes strict and uniform application of IFRS. The IFRIC assists the IASB in achieving international convergence of accounting standards by working with similar groups supported by national standard setters to reach similar conclusions on open questions about the application of individual standards. Each IFRS contains the following components: objective of the standard, scope of application, defines recognition and measurement and publication.

International accounting standards have the purpose of a more versatile, easier and better understanding of financial statements with the main goal of providing data and information for analysis and unhindered IAS in fact represent a kind of harmonization of different accounting regulations related to the preparation and presentation of financial statements, which serve as a basis for making economic decisions. Standards as a term are used in almost all fields of engineering, technology, natural sciences and other fields.

2.2 Quality of financial reporting

Financial reporting, over a long period of time, has undergone thorough changes with the aim of creating better quality financial reports in accordance with the requirements of modern accounting and the accepted requirements of financial reporting. The need to equalize balance sheet positions in the compilation, presentation and publication of financial statements was created as an obligation if a certain degree of harmonization and standardization of financial reporting is to be achieved on the international scene (Novajlija Islambegović, 2018). The quality of financial reporting is also assessed in the context of whether the reports comply with applicable accounting rules and standards, such as IAS (International Accounting Standards) or IFRS (International Financial Reporting Standards). Compliance with these standards enables consistency and precision in financial reporting.

There are four main characteristics of financial statements: (Conceptual framework for financial reporting, p.25-42)

- comprehensibility
- importance
- reliability
- comparability.

Understandability is an improving qualitative feature of financial information. Classifying, describing and presenting information in a clear and concise manner makes it understandable. Some phenomena are by their nature complex and it is not easy to make them understandable. Excluding information about such phenomena from financial statements could contribute to making the information in these financial statements easier to understand. Importance refers to the relevance and usefulness of information provided to users of financial statements. In the context of quality, importance means that financial statements must contain information that is significant for making business decisions and that can influence the future decisions of users.

Reliability implies that information in financial statements can be verified and confirmed. This means that reports must be based on objective data, while minimizing subjective assessments or manipulations.Comparability is a qualitative feature that enables users to identify and understand similarities and differences between items. Unlike other qualitative characteristics, comparability does not refer to only one item. A comparison requires at least two items.

2.3 Impact of IAS on accounting practice

IAS significantly influence accounting practice because they improve the quality and reliability of financial statements, but also bring about the need for constant harmonization and training of accountants. IRS/IFRS standards enable companies to report in accordance with uniform rules, which increases the transparency of financial statements. This enables users (investors, analysts, regulators) to more easily understand and compare financial data between companies, regardless of the country of origin. One of the most important influences of IAS/IFRS is the direction towards harmonization of accounting methods. According to IFRS, there are precise requirements regarding the methods of revenue recognition, valuation of assets and liabilities, and harmonization of reporting procedures. Also, IFRS mandates estimates that oblige companies to apply the most appropriate methods and estimates for accounting reports, such as estimates of the useful lives of assets and liabilities.

2.4. Previous research on the impact of IAS/IFSI on the quality of financial reporting

In their work, Gabrić and Palac showed that the most common areas of significant misstatements in the financial statements of companies in the Federation of Bosnia and Herzegovina relate to the items of value adjustments of short-term receivables and impairment of fixed assets and inventories, and that in the application of IFRS/IAS in the Federation of Bosnia and Herzegovina, with regard to the established quality of financial statements, the most common deviations are from the application of IAS 36 - Impairment of Assets, IAS 2 - Inventories and IAS 39 - Financial assets: recognition and measurement. Authors Bašić, Benina and Isaković-Kaplan investigated the impact of the application of International Financial Reporting Standards (IFRS) and International Accounting Standards (IAS) in Bosnia and Herzegovina, with special emphasis on the impact of accounting policies on the quality of financial reporting.

They identified two key problems related to the insufficient publication of accounting policies, as well as the lack of notes to financial statements and the inadequate presentation of accounting policies in financial statements. Both problems call into question the quality and integrity of financial reports in BiH and make it difficult for external users to review and understand the reports. In their work, the authors Mamić Sačer and Ramač Posavec investigate the challenges faced by Croatian companies during the implementation of international financial reporting standards (IFRS) and find out about the key problems faced by companies. The results of the research showed that the frequent changes and additions to the standards have a negative impact on maintaining the up-to-dateness and compliance of financial statements by accountants. This problem brings with it a lack of professional knowledge and training for the correct application of standards, which will result in higher costs for the company.

3. Methodology, analysis and discussion of research results

3.1. Empirical research methodology

In this subchapter, the methodology of the research conducted using the survey questionnaire technique will be presented. The primary goal of the research was to find

out about the impact of the application of IAS/IFRS on the quality of financial reporting, the reduction of accounting manipulations and the comparability of data. The goal is to determine the contribution of these standards to the transparency and accuracy of financial statements. The research is quantitative, based on a survey questionnaire that was created using a Google Forms form. The research sample consists of 55 respondents from the fields of finance, accounting and auditing, from different types of companies, with different levels of experience in the area of the Una-Sana Canton. The research was conducted in the period from February 18, 2025 to March 10, 2025. year. Through e-mail and social networks, the link was sent to potential respondents. Data were analyzed using descriptive statistics and correlation analysis. Respondents filled out a closed online questionnaire, which contained 8 questions. The survey questionnaire consisted of several sections: general information about the respondents, Likert scale (1-5) on the perception of the impact of IAS/IFRS and questions (Yes/No/Partially) about the application and challenges of IAS/IFRS. The processing of the collected data was done through the available charts and tables in the MS Excel package.

3.2. Research results

This subchapter shows the profile of respondents according to the position in the company, the size of the company and the level of experience in accounting and finance. Most respondents are accountants from medium-sized companies, with 0-5 years of experience, which gives an insight into the perspective of experts who directly deal with financial reporting. The results are presented in Table 1.

Table 1. Demographic characteristics of the sample

Category	The most common answer	N	%
Position in the company	Accountant	37	67,3
Company size according to income	Medium	26	47,3
Experience in accounting and finance	0-5 years	32	58,2

Source: creation of the author

Most respondents are accountants (67.3%), which means that the answers are mainly from experts who work directly with IAS/IFRS. Most respondents come from medium-sized companies (47.3%), while small and large companies are less represented. This may mean that medium-sized companies have the greatest interest

or challenges in applying IAS/IFRS. Experience in finance and accounting is dominated by people with 0-5 years of experience (58.2%), which indicates that the answers come from younger professionals or newer employees.

To the question "What are the main challenges in applying IAS/IFRS?" out of 55 respondents, 35 respondents (63.6%) chose the answer "complexity of standards" and 20 respondents (36.4%) "lack of training" (Figure 1).

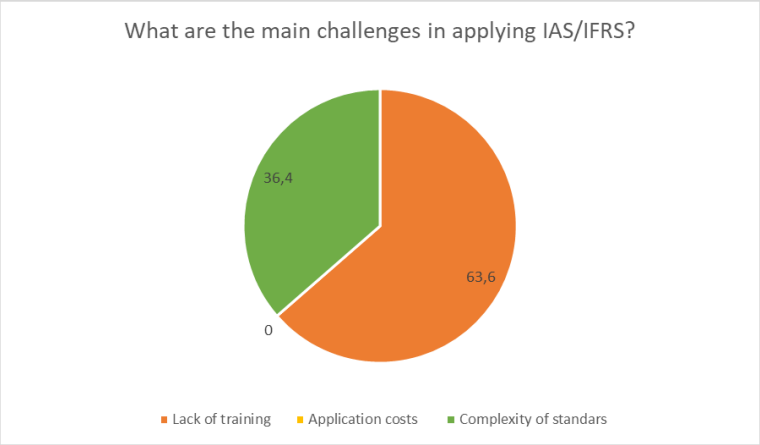

Figure 1. Challenges in applying IAS/IFRS

The next question was formed by a Likert scale (1 - Not at all to 5 - To a great extent) where respondents were asked to rate their level of agreement with certain statements about the application of IAS/IFRS. The results are presented in Table 2.

Table 2. Perception of the impact on IAS/IFRS

Question	Not at all	Little	Moderately	Significantly	To a great extent
To what extent does the application of IAS/IFRS improve the accuracy and reliability of financial statements?	0,0%	10,9%	18,2%	36,4%	34,5%
How much more transparent are financial statements after	0,0%	3,6%	29,2%	34,5%	32,7%

applying IAS/IFRS?					
How interested are international investors in companies that apply IAS/IFRS?	3,6%	7,4%	38,2%	25,4%	24,4%

Source: creation of the author

Respondents largely believe that IAS/IFRS improve the accuracy of financial statements and transparency (over 65% of positive responses). They are less certain that these standards increase the interest of foreign investors (only 50.9%). This may mean that factors other than standards influence investors' decisions.
The next group of questions consisted of four questions to which respondents could give the offered answers Yes/No/Partially (Table 3).

Table 3. Application and challenges of IAS/IFRS

Question	Yes	No	Partially
Do you think that IAS/IFRS are clear and applicable in practice?	27,3	5,4	67,3
Does the application of IAS/IFRS reduce the possibility of accounting manipulations?	52,7	7,3	40,0
Does the application of IAS/IFRS facilitate the comparability of your financial data with other companies in your sector?	61,8	5,4	32,8
Do you think that additional education could improve the application of IAS/IFRS?	94,5	0	5,5

Source: creation of the author

Respondents believe that IAS/IFRS help reduce accounting manipulations and improve data comparability. However, as many as 67.3% of respondents (37 out of 55) believe that the standards are not completely clear and applicable in practice, which may indicate the need for further training and adjustment. Additional education was almost unanimously rated as useful, as many as 94% of respondents thought it would improve the application of standards.

At the end of the questionnaire, respondents could propose measures to improve the application of standards in the company. Some of the proposed measures are: employee education, improvement of accounting systems, increased communication with external auditors, simplified explanations of IAS/IFRS content, implementation of quarterly and half-yearly analyzes of financial statements to check compliance with standards, improvement of cooperation with all sectors within the company, etc.

3.3. Discussion of research results

The discussion of the research results is based on the analysis of respondents' answers regarding the application of IAS/IFRS in companies. Respondents are mostly accountants with 0-5 years of experience, which suggests that the answers come from young professionals who are directly engaged in financial reporting. Most respondents come from medium-sized companies, which may indicate the specific challenges and needs of this segment in the application of international accounting standards. Given the dominance of medium-sized companies in the sample, it is possible that these companies recognize the importance of IAS/IFRS due to their size, business complexity and the need for better financial reporting and comparability with the competition. According to respondents, the greatest challenge in the application of IAS/IFRS is the complexity of the standards (63.6%), while the lack of training was identified as another important problem (36.4%).

These results indicate the need for greater educational investments and better training of employees, in order to facilitate the application of standards and reduce potential problems in practice. Also, the complexity of the standards themselves can be an obstacle for easier adoption and implementation, which can affect the accuracy and reliability of financial statements, which, on the other hand, is one of the goals of applying IAS/IFRS. According to the answers, 51% of the respondents believe that the standards reduce accounting manipulations, while 41% believe that their impact is not complete. This suggests that although IAS/IFRS improve the integrity of financial data, there is still room for abuse. However, 67.2% of respondents believe that IAS/IFRS are not completely clear and applicable in practice, which indicates the need for additional training and adaptation of the standards to the specifics of the company.

4. Conclusion

Based on the data analysis, we can make the following conclusion regarding hypothesis H0: The adoption of IAS/IFRS positively affects the quality of financial reporting, reducing opportunities for accounting manipulations and increasing the comparability of financial data at the international level. The majority of respondents believe that IAS/IFRS improve the accuracy and reliability of financial statements (71% gave high marks). Also, the standards contribute to greater transparency of financial statements (67% of respondents evaluate them positively). These results confirm the part of the hypothesis that refers to the improvement of the quality of financial reporting. 51% of

respondents believe that the application of IAS/IFRS reduces the possibilities for accounting manipulations, while 41% believe that their impact is partial.

This result indicates a positive, but not absolute effect of IAS/IFRS in suppressing manipulations - although there is an improvement, some respondents still see room for abuses. 61% of respondents believe that IAS/IFRS facilitate the comparability of financial data at the international level. This result confirms the part of the hypothesis related to the standardization and comparability of financial data. Ultimately, we conclude that the main research hypothesis is partially proven. The statistical analysis confirmed that the application of IAS/IFRS has a positive effect on the quality of financial reporting and increases its comparability, but the effect on reducing manipulations has not been fully confirmed.

In conclusion, although there is significant progress in the application of IAS/IFRS in companies, the research showed that there is a need for further education, training and adaptation of standards to the specific needs of companies. Given the challenges in application, such as the complexity of standards and lack of training, companies should invest in employee education and improvement of accounting systems in order to implement IAS/IFRS more efficiently and improve the quality of their financial statements.

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Territorial reform of local self-government units in Bosnia and Herzegovina – needs and opportunities

Jasmin Hušić and Suan Islamović

Faculty of Law, University of Bihac, Bihac, Bosnia and Herzegovina

E-mail: jhusic77@gmail.com

Abstract. In the article, the authors analyse the size of local self-government units in Bosnia and Herzegovina in the context of its influence on the exercise of the right to local self-government and compare the territorial parameters of local self-government units in Bosnia and Herzegovina with the territorial parameters of local self-government units in the European Union member states. Based on the analysis conducted and the established parameters, the authors conclude whether there is a need for territorial reform of local self-government units in Bosnia and Herzegovina, what the possibilities for implementing territorial reform are, and what alternative solutions exist, if the reform proves necessary but difficult to implement. The authors use statistical, normative, and deductive methods in the research.

1. Introduction

The essence of local self-government units (LSGU) lies in their ability to meet the needs of citizens as effectively as possible within that level of government. One of the fundamental principles of local self-government, established by the European Charter on Local Self-Government, is the principle of subsidiarity. This principle emphasizes the importance of carrying out tasks at a level closest to the citizens. Certain preconditions must be met for local self-government units to fulfil this role. These conditions include social or human capacity, intellectual or professional expertise, and financial capacity, encompassing the economic foundations necessary to develop and fund local government responsibilities. Meeting these preconditions is essential for addressing the needs of citizens in a developmental context.

The size of the territory is a very important prerequisite for the functioning of local self-government units, which essentially represents one of the segments of financial capacity because, in addition to being a living space, it is a potential source of natural resources. For this reason, it is important that the local self-government units have an adequate and at least approximately equal area of their own territory, but also that the territory, in qualitative terms, should be approximately equal and sufficiently endowed. In practice, this is often not the case. Sometimes the reasons for unevenness are conditioned by natural factors, and sometimes by artificial restrictions. Such unevenness also exists in Bosnia and Herzegovina. The aforementioned facts inevitably point to the necessity of dealing with this issue to find the best solutions for harmonizing the underlying principles for implementing local self-government

principles in all local self-government units. Using statistical, normative, and deductive methods, including a previous analysis of the situation in B&H, this paper offers some potential solutions for equalizing the potential of local self-government units in B&H.

2. Territorial size of local self-government units in Bosnia and Herzegovina

Considering the specificities of local communities in Bosnia and Herzegovina (B&H), which have become local self-government units by granting the status of self-government, it is clear that there must also be certain differences in the size of local self-government units. Thus, in B&H, there are significant differences between individual municipalities and cities in the size of the territory, number of inhabitants, financial capacities, personnel availability, and other characteristics, which must surely be reflected in the quality and extent of exercising the competences of local self-government units. Certainly, in this sense, the realization of competences should be seen as the realization of the rights of municipalities and cities, or more precisely, the rights of citizens to local self-government.

Unlike other neighboring countries, the former republics of the SFR Yugoslavia (SFRY), B&H tended to retain the structure of larger municipalities as it had in the SFRY. At that time, there were 109 municipalities in the territory of B&H, whereas today there are 143. For comparison, in the territory of Croatia during the SFRY period, there were 115 municipalities and cities, while today there are as many as 555. Accordingly, the average municipality in the Socialist Republic of Bosnia and Herzegovina (SR B&H), covered 470 km^2, whereas today it encompasses approximately 358 km^2, indicating a reduction in average size by about 31%. In the case of the Socialist Republic of Croatia, the average municipality previously covered 492 km^2, compared to just 102 km^2 today, representing a reduction of around 382% in the average municipal size. A similar pattern is observed in the case of the Republic of Slovenia. The Socialist Republic of Slovenia had 65 municipalities, each averaging approximately 312 km^2 in size. Today, with 212 municipalities, the average size has decreased to roughly 96 km^2, indicating a reduction of about 225% in comparison to the pre-war period.

As shown in Table 1, which was created for comparison with pre-war municipalities, the number of municipalities in B&H is significantly higher today than it was in the former Socialist Republic of Bosnia and Herzegovina, based on data from 1988. It is also evident that the number of small municipalities - defined as those with an area of up to 100 km^2 - has increased substantially. Today, there are 26 such municipalities, compared to only 5 in SR B&H. All other municipalities at that time had an area greater than 100 km^2.

The largest number of municipalities in B&H, i.e., 18.2%, are in the range of 200 – 299 km^2, followed by municipalities of 300 – 399 km^2, representing 16.8%. The situation was similar in the SR B&H, where 19 municipalities, or 17.4%, fall in the 200 – 299 km^2 range, and 21 municipalities, or 19.3%, are in the 300 – 399 km^2 range. Therefore, the majority of municipalities in SR B&H are in the 300 – 399 km^2 range, while in B&H, most are in the 200 – 299 km^2 range. It can be concluded that the highest concentration of municipalities is within the 200 – 399 km^2 range, accounting for 35% in B&H and 36,7% in SR B&H.

Table 1. Comparative overview of the size of municipalities in SR B&H and B&H.

Area (km2)	F B&H	RS	B&H	Percentage (143 municipalities)	SR B&H (1988)	Percentage (109 municipalities)
Up to 49	8	5	13	9	3	2,7
50 - 99	5	8	13	9	2	1,8
100 – 199	14	8	22	15,4	11	10,1
200 – 299	17	9	26	18,2	19	17,4
300 – 399	16	8	24	16,8	21	19,3
400 – 499	4	5	9	6,3	12	11
500 - 599	6	5	11	7,7	11	10,1
600 – 699	0	7	7	4,9	7	6,4
700 – 799	3	3	6	4,2	8	7,3
800 – 899	0	4	4	2,8	4	3,6
900 – 999	3	0	3	2,1	5	4,6
1000 – and more	3	2	5	3,5	6	5,5
Total	79	64	143	100%	109	100%

It is important to note that municipalities have largely retained their original sizes from the time of the SR B&H. The fragmentation of municipal territories primarily resulted from the demarcation of the "Dayton line," which separated the different

entities within Bosnia and Herzegovina. For example, the Municipality of Doboj is divided into three parts: Doboj South, which is part of the Zenica-Doboj Canton; Doboj East, in the Tuzla Canton; and Doboj, located in the Republika Srpska (RS) entity. In a few cases, new municipalities were established due to specific merits and evolving circumstances, such as the formation of the Municipality of Bužim, which was previously part of the Municipality of Bosanska Krupa.

3. Territorial size of local self-government units in the member states of the EU

After the exit of the United Kingdom of Great Britain and Northern Ireland, there are now a total of 27 member states in the European Union (EU). This significantly alters the total number of LSGUs, as well as the characteristics of local self-government within the EU, given the number of LSGUs and the specificities of local self-government in the United Kingdom. Although the number of local LSGUs in the EU changes relatively frequently, this is understandable due to the large number of countries and the vast number of LSGUs involved.

According to data from the Council of European Municipalities and Regions (CEMR), 92,133 LSGUs were formed in 27 member states. By dividing the total area of all member states by the number of local LSGUs, an average area of 45.8 km^2 per LSGU is obtained, meaning there is one LSGU per 45.8 km^2. However, if the average size of LSGUs for each member state is calculated and then the mean of these averages is taken, the resulting average size (i.e., the average of the average LSGU sizes) is 258 km^2. Accordingly, the average LSGU in the EU, at 258 km^2, is significantly smaller than the average LSGU in Bosnia and Herzegovina, which is 358 km^2—thus, larger by a full 100 km^2. Table 2 shows that the concentration of EU member states by average size of LSGUs is in the category of up to 49 km^2. Thus, as many as 11 out of 27 member states (or 40.7%) have an average size of municipalities below 50 km^2. Almost 60% of member states have an average LSGUS below 100 km^2. As previously emphasized, 35% of municipalities in B&H are concentrated within the range of 200 to 399 km^2.

What additionally specifies LSGUs in the EU, when it comes to their size, is that there are huge deviations both within the member states and in the mutual comparison of the member states. For example, in France, the municipality of Castelmoron-d'Albret, which has only about 50 inhabitants, covers an area of just 0.0354 km^2. On the other hand, the municipality of Arles is the largest in metropolitan France, with an area of 759 km^2. More broadly in France, the municipality of Maripasoula in French Guiana, home to fewer than 4,000 residents, covers an area of 18,360 km^2. A similar pattern can be observed in Finland, where the largest municipality, Inari, spans 17,333 km^2, whereas at the other extreme, the municipality of Kauniainen covers only 6 km^2.

Similarly, when comparing data between EU member states, significant disparities become apparent. For instance, France, with an average municipality size of 17.26 km^2, predominantly consists of small municipalities. In fact, over 5,000 French municipalities have an area smaller than 0.05 km^2. In contrast, other countries such as Sweden, Finland, and Iceland have substantially larger local self-government units (LSGUs). Finland's average municipality size exceeds 1,000 km^2, Iceland's average municipality measures nearly 1,400 km^2, and Sweden's average municipality exceeds

1,500 km². Malta has the smallest average municipality size in the EU, with 68 municipalities averaging 4.64 km² each. Conversely, Sweden has the largest average size, with 290 basic LSGUs (first-level local governments), averaging 1,512.32 km² per municipality. Therefore, there is a vast range of municipality sizes across the EU. The median is represented by Romania, where the average municipality size is approximately 74.94 km², and the number of basic LSGUs (first-level local governments) exceeds 3,000.

Table 2. Average size of local self-government units in EU countries.

Area (km2)	Number of EU countries	Percentage
Do 49	11	40,7
50 - 99	5	18,5
100 – 199	3	11
200 – 299	1	3,7
300 – 399	0	0
400 – 499	3	11
500 – 599	1	3,7
600 – 699	0	0
700 – 799	0	0
800 – 899	0	0
900 – 999	0	0
1000 and more	3	11
Total	27	100%

The situation is similar when considering all European countries, not just EU members. Malta has the smallest average municipality size, while Sweden has the largest. The median size is found in Slovenia, where the average municipality covers 95.62 km² out of a total of 212 municipalities. In the EU, there is an LSGU for every 45.8 km², whereas across Europe as a whole, there is one LSGU for every 49.14 km². This means that LSGUs in Europe are generally larger than those in the EU. This trend is further supported by the average sizes of municipalities throughout all European countries, which stands at 306.2 km². In contrast, when considering only EU member

states, the average size is 258 km^2. Although the average size of municipalities in Europe is significantly larger than that in the EU by 48.2 km^2, it's important to note that the average size of municipalities in B&H is still considerably larger than the European average by 51.8 km^2.

4. Criteria for determining size

One of the most important issues in the formation of LSGUs and the organization of local self-government in general is the issue of size. Simply put, the dilemma is which approach to adopt: the "large LSGUs" model, which, as highlighted by Pavić [6], assumes that such units are capable of performing an increasing number of modern, differentiated, and specialized administrative tasks; or the "small LSGUs" approach, which emphasizes the advantages of local self-governance in terms of accessibility to local services and similar benefits. Of course, the issue of the size of the territory of LSGUs has also been addressed by other authors, either by describing its characteristics and the significance of these characteristics for the development of local self-government, or by attempting to define certain principles or criteria that the legislator should or must apply and respect when determining the boundaries of the areas of local communities that will be granted or have already been granted the status of local self-government.

Eugen Pusić argues that the division of a state's territory into narrower regional and local units should satisfy four criteria: (1) to cover the entire national territory without any gaps; (2) to achieve as much uniformity as possible in size and location among units of the same type and level; (3) to ensure maximum economic and financial self-sufficiency of all units; and (4) to facilitate easier access for the population to local authorities and services [3]. Unlike Eugen Pusić, Inge Perko-Šeparović [5] identifies seven factors that determine the size of local self-government units (LSGUs): (1) geographical or natural, (2) temporal, (3) economic-technical, (4) political, (5) urbanization-related, (6) sociological, and (7) administrative factors. Unlike Eugen Pusić, who defines criteria, and Inge Perko-Šeparović, who identifies factors upon which territorial division should be based, Stjepan Ivanišević [3] explains and distinguishes between the general principles of territorial division of the state's territory and the principles specifically related to local self-government units.

As general principles, Ivanišević emphasizes: a) comprehensiveness (the network of local units should encompass the entire state territory without a remainder); b) stability (the basis of local self-government should be permanent and stable and without frequent changes in its borders); c) rationality (territorial division must be based on objective and realistic grounds, and not be the result of the relationship of political forces at a given moment or a series of other random circumstances; d) organizational adequacy of territorial division (clear territorial demarcation of local units, established line of vertical connection and optimal range of contacts and range of vertical connection) [3]. In addition to the general principles of territorial division mentioned earlier, Ivanišević [3] also outlines principles related to local self-governing units: (a) integrity of the local unit, meaning that the boundaries should form a coherent whole, distinct from surrounding units; (b) uniformity of local units, which implies that

units should be as equal as possible in terms of size and status; (c) financial capacity and autonomy, requiring that the local unit has sufficient own resources to finance its programs, activities, and institutions; (d) democratic governance, whereby the territory should allow citizens to participate in managing local affairs, formulating local policies, and exercising democratic oversight; and (e) accessibility of local services, ensuring that such services are readily available to residents.

A decision on unified criteria for establishing new municipalities or modifying the boundaries of existing ones in the F B&H (1995) sets out specific conditions aimed at preventing the creation of non-functional and unsustainable municipalities, including: (a) a municipality may be established in an area where the conditions for local self-government, as defined by the Constitution of the Federation B&H, are met; (b) the area must represent a unified spatial or natural geographical whole, composed of one or more settlements connected by infrastructure enabling smooth internal communication; (c) the area must have economic and other conditions sufficient to ensure a certain population can meet their individual and collective needs and interests; (d) cantonal law must specify the minimum population needed to establish a municipality, not exceeding 4,000 residents; (e) new municipalities or boundary changes must not create enclaves outside any municipality that cannot become independent municipalities themselves; (f) a new municipality cannot be established, nor can boundaries be changed, in areas where more than 50% of one ethnic group has been displaced, unless consent is obtained in the Parliament of F B&H following the procedure for decisions affecting the vital interests of any constituent people; and (g) the name of a new municipality is determined based on the name of the settlement proposed as its administrative center or a relevant geographical feature.

Thus, the Decision took into account the conditions for the realization of local self-government, the economic capacities that would be the economic basis for the fulfillment of needs, the meaningfulness of the geographical area so that the territory of the municipality would form a meaningful natural unit, as well as the fact that the formation of new municipalities does not leave out a territory (enclave) that does not have the conditions to be a municipality and has not been annexed anywhere. Likewise, care was taken to protect the vital interests of the constituent nations. However, the stated criteria are imprecise and general. For example, what does the criterion mean that "on the territory of the municipality, there should be economic and other conditions so that a certain number of the population can satisfy personal and common needs and interests"? What is the "certain number of population"? What are these "personal and common needs"?

Therefore, while it is both necessary and inherently challenging to define criteria, applying them in practice is even more difficult - particularly when an additional prerequisite is the existence of an artificially drawn boundary (inter-entity or inter-cantonal) that administratively divides a given territory without considering whether the resulting separate areas will retain, in qualitative terms, the necessary conditions for adequate functioning and fulfillment of the responsibilities for which they are being constituted; for example, in the FB&H, the Law on the Establishment of New Municipalities in the FB&H and the Alteration of the Territories of Municipalities Divided by Inter-Entity and Inter-Cantonal Boundaries led to the creation of the

following municipalities: Doboj Istok, Doboj Jug, Dobretići, Domaljevac-Šamac, Foča, Pale, Sapna, Teočak, Usora, and Ravno. This raises the question of whether municipalities formed in such a manner can truly meet all the criteria of justification and autonomy required for a given area to function as a municipality in which local self-government is to be exercised for all its residents, in accordance with the Law on the Principles of Local Self-Government in the FB&H and the provisions of the European Charter of Local Self-Government. This question must, of course, be considered in the context of all the conditions under which these municipalities operate - most notably their population size (e.g., Doboj Jug: 4,137; Doboj Istok: 10,248; Teočak: 7,424), their very limited territory and lack of substantial natural resources necessary for development, and their municipal budgets (e.g., the 2025 budget of the Municipality of Teočak was 6,300,000 KM; Doboj Istok: 7,600,000 KM; Domaljevac-Šamac: 4,300,000 KM).

The extent to which the Municipality of Pale can fulfill its obligations to enable citizens to exercise local self-government and their rights in areas like culture, education, quality of life, security, social needs, and others is uncertain. Its 2025 budget was about 3,900,000 BAM, with over 3,352,000 BAM coming from current and capital transfers from higher levels of government. The municipality's tax and non-tax revenues total just over 500,000 BAM. This suggests that without support from higher government levels, the municipality is essentially non-functional. Although not all these areas are directly within the municipality's responsibility, it must have the capacity to implement, organize, or contribute to meeting all citizens' needs within its territory, including those under other government levels' jurisdiction. For example, by handling its own duties, such as public cleanliness and waste disposal, the municipality directly supports public health. Additionally, it is responsible for assessing the performance and service quality of healthcare institutions and securing funding to improve them. Concerning security, while public order and safety mainly fall under the jurisdiction of cantonal and federal interior ministries, municipalities are tasked with analyzing the state of public order and safety and proposing measures to the appropriate authorities.

Almost no area of life and work exists in which local self-government units cannot, within their competencies, contribute in some way to improving the quality and standard of living of their citizens. Certainly, to handle such a wide range of responsibilities, municipalities must have intellectual, social, and financial capacity; otherwise, the quality and scope of their activities will stagnate or decline, inevitably affecting the quality of life and work of the residents. Undoubtedly, the size of local self-government units is highly significant, especially in the economic, sociological and legal context, as a prerequisite for the development, stability, and existence of local communities and self-governance in a specific area. Naturally, the size of the territory should be considered in the context of all its geographical features and qualities, such as: a) the richness and importance of mineral, water, solar, forest, and other resources b) climatic conditions favorable for tourism, certain sports, agriculture, fruit growing and overall comfortable living; c) transport connectivity with surrounding areas, the state of transport infrastructure and the possibility of road connections throughout the entire territory; d) relief, i.e., predominance of lowlands or mountainous areas, and fragmentation by watercourses and wetlands; and e) geopolitical position, including

proximity to state borders, major economic and cultural centers, influence and interest of economic, military, commercial centers of power, among other characteristics.

However, it is very challenging, if not impossible, to establish precise and comprehensive criteria for defining the territory of LSGUs. As previously noted, many authors and legislators have attempted to guide the process of forming LSGUs with criteria and principles aimed at creating at least somewhat sustainable and functional units capable of organizing life in their territory and enabling their citizens to enjoy local self-government. The authors of this paper believe that when constituting LSGUs to achieve self-sustaining and functional entities, several fundamental territorial criteria must be considered: a) territorial compactness, meaning the LSGU's territory should be continuous and not fragmented into separate parts; b) territorial coherence, which requires the territory to have a logical shape that does not obstruct communication, maintenance, or access to key infrastructure and natural resources; c) territorial sufficiency, ensuring the area is appropriately sized relative to its population to avoid extreme population density that could strain services and reduce quality of life; d) resource capacity, meaning the territory should have significant natural resources or economic potential - such as agricultural land, waterways, mineral deposits, or tourist attractions - that can support income generation and sustainable development.

After the constitution of the LSGUs, in addition to the initial constitutive criteria, it is necessary to meet the functional criteria:

a) Organic capacity – that administrative bodies and other services (municipal/city and other services) can adequately respond to citizens' requests on time, within a reasonable or legal deadline, which implies equality of access, regardless of which part of the LSGU the citizens live in. Thus, LSGUs should not include populated areas to which municipal/city and other services (utility companies, emergency services, etc.) cannot access and perform their responsibilities on time. In such a case, it is necessary to additionally equip the services or such inhabited places, regardless of the number of households or inhabitants to be relocated or annexed to another, closer LSGU. Likewise, all services should be staffed and materially and technically equipped to be able to perform their duties in the entire territory and towards each citizen.

b) Communal-infrastructural equipment - construction of communal infrastructure. Populated places should be equipped with the necessary communal infrastructure without major deviations from the average equipment of all populated places. Under communal infrastructure is understood: traffic infrastructure (streets, roads, railways, airports, ports), distribution infrastructure (water supply, sewerage, electric lines, gas pipes, heating pipes), communication and information infrastructure (telephone networks, postal networks, Internet networks, television), horticultural infrastructure (green areas, parks, forests, etc.).

c) Income generosity – ensured necessary and adequate sources of income (tax and non-tax). LSGUs must have secured permanent financial resources that will be sufficient for the functioning of all services, maintenance of communal infrastructure, and improvement of the quality of life in the fields of culture, education, health, security, etc., within the scope of competence.

It is clear that the application of the above criteria is not simple and that in practice it encounters certain difficulties. However, deviations that would make the local

government dysfunctional or significantly reduce the quality of life in the area of such a local government should be avoided as much as possible. Any deviation should be compensated for in some way, either by continuous state intervention (e.g. subsidies) - which is the last option, since this makes the local government dependent on higher levels, making its functioning uncertain, or by one-off or repeated intervention aimed at building and establishing a system (e.g. construction of communal infrastructure, development of economic potential, etc.), which will strengthen and make the local government independent so that it can freely exercise its responsibilities. If this deviation cannot be resolved in this way, a solution can be sought in the amalgamation of settlements and areas into a more functional and independent whole.

5. The need for territorial reform of local self-government units in Bosnia and Herzegovina

The LSGUs in B&H have equal competences - a monotypic structure of local self-government, except for two cantons where deviations from this monotypic structure are possible. Specifically, Article 51 of the Constitution of the Bosnian-Podrinje Canton stipulates that municipalities may have different competencies depending on the overall policy of functioning and development of the Canton, as well as the economic, spatial, and other positions of individual municipalities. Similarly, the possibility of a polytypic organization of municipalities is allowed in the Sarajevo Canton. Given that LSGUs have equal competences, rights, and obligations, this clearly indicates that LSGUs should have at least approximately equal preconditions for the realization of these obligations; approximately equal budgets, human capacities, material and technical capacities, etc. On the other hand, LSGUs should have approximately the same needs, for example: approximately the same length of roads for construction and maintenance, approximately the same built educational infrastructure (schools, kindergartens, cultural centers, etc.), approximately the same need for the construction of business and residential buildings, approximately the same population density, etc.

In B&H, there are significant disparities among LSGUs regarding area, revenues, population, needs, and other characteristics. For instance, the municipality of Bosansko Grahovo has 2,449 inhabitants and spans an area of 780 km^2, resulting in a population density of only 3.1 inhabitants per km^2. In contrast, the municipality of Centar has 55,181 residents living in an area of 33 km^2, yielding a density of 1,672.1 inhabitants per km^2. Furthermore, Bosansko Grahovo's budget for 2025 is projected to be 3,205,412 KM, with tax and non-tax revenues totalling only 1,738,710 KM. Conversely, the budget for the municipality of Centar in 2025 is 83,390,000 KM, with tax and non-tax revenues amounting to 78,669,712 KM. Therefore, when comparing the tax and non-tax revenues of these two municipalities, it follows that Bosansko Grahovo has 710 KM per inhabitant, or, in terms of area, 2,229 KM per km^2. On the other hand, the municipality of Centar has 1,426 KM per inhabitant, which is double that of Bosansko Grahovo, and even 2,383,930 KM per km^2, which is 1,069 times higher than that of Bosansko Grahovo. A similar situation exists with other small and large municipalities such as Trnovo in the FB&H (1,502 inhabitants/338 km^2), Trnovo in the RS entity (2,050 inhabitants/116 km^2), the Municipality of Petrovac (361 inhabitants/155 km^2),

the Municipality of Pale in the FB&H (904 inhabitants/86.4 km^2), the Municipality of Kupres in the RS entity (300 inhabitants/48 km^2), the Municipality of Istočni Drvar (79 inhabitants/75 km^2), and other small municipalities. In contrast, there are larger municipalities and cities such as Banja Luka (185,000 inhabitants/1,238 km^2), Bijeljina (107,715 inhabitants/733 km^2), Novi Grad (118,553 inhabitants/47 km^2), Tuzla (111,000 inhabitants/294 km^2), and others.

It is entirely reasonable to conclude that there is significant unevenness in the area, population, and revenues of individual LSGUs, and that this must impact the quality and quantity of services provided, i.e., the execution of LSGU responsibilities. Indeed, it is not reasonable to expect an equal quality of life, which depends on the provision of municipal and city services, across all LSGUs, given the drastically different conditions under which these services operate. Building communal infrastructure over an area of several hundred square kilometers with a total budget of a few million KM, compared to building infrastructure over an area of several dozen square kilometers with a total budget of several tens of millions KM, is incomparable and, from the perspective of the planned LSGU constitution, an unacceptable basis for LSGU functioning and the realization of local self-government in general. Therefore, considering any criteria (Pusić, Perko-Šeparović, Ivanišević, as well as those established by the 1995 Decision on unified criteria for constituting new municipalities or changing the boundaries of existing municipalities in the FB&H), it is unacceptable to place citizens and LSGUs in such an unequal position.

Statistical indicators such as population size, area, revenues, and development coefficient, along with actual conditions including fragmented settlements, weak economic development, lack of infrastructure connectivity, and limited resources in certain LSGUs in B&H, clearly indicate the need for intervention by state and entity authorities. This intervention should focus on reforming or otherwise systemically equalizing the foundational developmental conditions of LSGUs, as well as other conditions necessary for carrying out their competencies. Additionally, the geostrategic position and connectivity with the surroundings, such as being located outside strategic infrastructure routes like highways and pipelines, and the distance from major economic, cultural, and other centers, further emphasize the urgency of such reforms.

6. The possibilities of harmonizing the conditions of development and functioning of local self-government units

Several questions need answers when deciding how to enhance local self-government. It is important to determine whether a single-level or multi-level local self-government system is preferred. Equally significant is the choice between large or small LSGUs, as well as whether a monotypic or polytypic structure of LSGUs is more suitable. In B&H, local self-government is organized as single-level and monotypic, featuring relatively large LSGUs, although certain exceptions exist in the formal-legal sense, such as in the Bosnian-Podrinje Canton and Sarajevo Canton. Furthermore, there are notable disparities among LSGUs regarding size, population, revenues, and overall development. However, many of these questions extend beyond the scope of this study; therefore, the focus will remain on potential methodological approaches for

harmonizing the foundational development bases of LSGUs and other conditions for exercising local self-government.

First and foremost, it is important to note that some municipalities are small in area, have a small population, and low revenues. Likewise, some municipalities are large in area but have a small population and low revenues. Some municipalities are relatively large in both area and population, yet have low revenues per capita and square kilometer. For example, the Municipality of Bužim covers an area of 129 km^2, which is larger than the average size of LSGUs in 60% of EU member states. It also has 19,340 inhabitants, exceeding the average population of LSGUs in 77% of EU member states. However, Bužim generates only 422 KM in tax and non-tax revenues per capita, or 63,339 KM per km^2. On the other hand, there are municipalities such as Doboj Jug, which is small with 4,137 inhabitants and just 10 km^2 in area. Nonetheless, the tax and non-tax revenues of Doboj Jug amount to 561 KM per capita (25% more than Bužim) and as much as 232,280 KM per km^2 (366% higher than Bužim). Therefore, population size and territorial area do not necessarily determine the economic development of a local government unit, as these factors can be compensated for. Nevertheless, they play a highly significant role in development.

Several options are available to mitigate the negative effects of an inadequate population size or insufficient resource capacity of a territory, aiming to equalize the capabilities and capacities of local self-government units in exercising local self-government. The first option is based on a polytypic organization of LSGUs. This approach allows certain municipalities to compensate for their weaknesses by adopting fewer responsibilities and adjusting their competencies to match their capacities. However, a drawback of this solution is the potential distancing of certain services from citizens, effectively legalizing a form of “discrimination” against such municipalities. The second option involves financial assistance from higher levels of government aimed at equalizing the human and material-technical capacities of LSGUs, which is essential for exercising local self-government and adequately providing services to citizens. The weakness of this solution lies in the ability or inability of higher authorities to financially compensate for municipal shortcomings. Additionally, such municipalities would remain dependent on and influenced by these higher levels of government. The third option is the amalgamation of individual LSGUs, which is considered the most acceptable solution, especially when combined with one of the above options. This would increase population size, territorial area, and consequently the resources necessary for development and the conditions needed to exercise local self-government. Moreover, necessary autonomy and financial independence from higher authorities would be maintained, ensuring that citizens are not disadvantaged compared to those in stronger LSGUs in accessing public services.

Therefore, by effectively consolidating municipalities in accordance with the territorial criteria or principles of territorial division outlined by Ivanišević [3]—inclusiveness, stability, rationality, organizational adequacy, territorial integrity, equalization, financial capacity and independence, democracy, and accessibility—dysfunctionality and unsustainability of individual municipalities could be avoided. At this level, interest fragmentation is minimal, and it is believed that local self-government in B&H can effectively address the negative consequences of sluggish

action by higher levels of government. In any case, the smart and ethical activation of the potential held by LSGUs regarding human (professional), organizational, and financial capacity must yield significant and beneficial effects reflected in citizen satisfaction. This implies genuine democracy and local self-government, which can be achieved through: a) constitutional and legal guarantees of significant competencies, b) financial stability, c) constitutionally and legally guaranteed effective and adequate protection, and d) agile self-organization of local self-government actors (citizens and institutions), ensuring a rapid and effective response to citizens' needs and threats arising internally (caused by system elements such as ineffective organization, non-performance of competencies, corruption, etc.) or externally, such as violations of the right to local self-government by higher levels of government [2].

7. Concluding remarks

Local self-government units, recognizing the complexity of socio-political relations at higher levels of authority, must assume the role of drivers for economic, cultural, and other forms of progress at the local level as more cohesive and compact entities. In this context, the significance of municipalities and cities should increase to ensure a desirable living environment. To effectively fulfil these responsibilities, LSGUs must have adequate preconditions to exercise their competencies, particularly concerning human resources and technical-material capacity. These preconditions should be equal or at least approximately balanced in type and scope across all LSGUs within a country. Therefore, beyond population size, the territorial basis must be appropriate and sufficient, not only in terms of area but also in qualitative aspects. In Bosnia and Herzegovina, a significant number of LSGUs lack comparable conditions for development and the exercise of local self-government, especially in meeting citizens' needs for public services. Consequently, it is essential to strengthen these local self-government units through amalgamation or, at a minimum, adequate financial support from higher levels of government. Ultimately, an alternative solution may involve differentiated obligations for local self-government units, i.e., a polytypic structure, which is considered less effective compared to amalgamation and the strengthening of local self-government units regarding territorial basis and population size.

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Persons out of employment with special reference to the labor-legal status of lawyers and notaries

Adna Zirić and Jasmina Bešlagić

Faculty of Law, University of Bihac, Bihac, Bosnia and Herzegovina

E-mail: ziricadna@gmail.com

Abstract. In contemporary legal systems, there is a growing need to regulate alternative forms of professional engagement that do not fall within the traditional employment relationship. The evolution of the labor market, the flexibilization of contractual relationships, and the nature of certain professional activities have contributed to the expansion of a category of individuals working outside the conventional employment framework. This paper explores the legal status of such individuals, focusing on lawyers and notaries, who bear obligations and responsibilities that integrate them into the broader legal and economic system. It examines the normative framework governing their work, including regulations related to labor law, contractual relations, social security, and taxation. Additionally, the paper discusses the peculiarities of their professional autonomy, their obligations toward clients and the state, as well as the economic and social challenges they face. Special attention is given to the distinctions between traditional employment relationships and work outside this framework, particularly regarding the legal implications of such status, including social security, pension insurance, and professional liability. A comparative legal analysis of regulatory models for lawyers and notaries across European Union legal systems is conducted to assess potential improvements to the legal framework in Bosnia and Herzegovina. The paper identifies key problems and challenges faced by lawyers, notaries, and other professionals working outside traditional employment structures. It also proposes legal solutions that could enhance their status, improve legal certainty, and strengthen social protection.

1. Introduction

Contemporary legal systems face increasingly complex challenges in regulating atypical forms of work that deviate from the traditional employment model. Dynamic changes in the labor market, technological advancement, the development of innovative business models, and processes of globalization have significantly contributed to the expansion of the practice of engaging persons outside of traditional employment relationships. This form of engagement is becoming increasingly prevalent across

various sectors of the economy and society, including professions with specific legal statuses such as lawyers and notaries. Persons outside of employment relationships represent a distinct category of labor subjects who perform their obligations based on civil-law contracts, such as contracts for specific work, temporary and occasional work contracts, copyright contracts, and other forms of engagement that do not establish an employment relationship under the positive provisions of labor law. [19] Such forms of engagement provide greater flexibility both for employers and for persons offering particular services, but at the same time raise numerous legal and social issues, especially regarding legal protection, realization of rights under the social security system, and fulfillment of tax obligations. Empirical and legal practice indicate that these models of engagement are often used as instruments to reduce labor costs, which in some cases leads to abuses and violations of the rights of engaged persons. In this context, the legal status of persons practicing so-called liberal professions—lawyers, notaries, architects, writers, and other experts operating outside the framework of classical employment relationships—becomes particularly relevant. These professionals act as independent practitioners with specific statuses within the legal system. What makes these professions unique is the combination of elements of independent activity with public-law functions and responsibilities, which further complicates their employment-legal status. Although they enjoy a high degree of professional autonomy and independence, one of the key issues remains how to ensure an adequate legal framework that enables employment security, effective protection of social and economic rights, as well as full accountability toward users of their services and society as a whole. Given that the legislative framework relating to these categories of subjects is often not precisely defined and largely depends on sector-specific regulations and special laws, it is of great importance to analyze the impact of existing normative solutions on their professional engagement. At the same time, it is necessary to identify the key differences between these forms of work and classical employment models in order to contribute to the development of a normative framework that better corresponds to the contemporary needs of the labor market and the legal security of engaged persons.

2. Concept and legal framework of persons outside employment relationships

In the contemporary legal order, particularly within labor law, there is a growing recognition of the diversity of work forms that cannot be categorized under the concept of a classical employment relationship. Certain subjects participate in work processes, perform specific tasks, and provide services without establishing a formal employment relationship as defined by the Labor Law. This category encompasses so-called persons outside employment relationships, whose engagement occurs outside the traditional labor law regime, within the scope of contractual, public-law, or special normative regimes. A common characteristic of such persons is the absence of some essential elements of employment relationships in their legal status, such as voluntarily

undertaken obligation to work for an employer, continuity of work, personal performance of work, work under the supervision and instructions of the employer, and remuneration as payment for work. Nevertheless, the nature of their engagement functionally approximates the notion of work, which is why these relationships are often referred to as quasi-employment relationships. One of the most evident examples of persons outside employment relationships are members of parliament, i.e., members of representative bodies of authority in Bosnia and Herzegovina. They perform their public functions based on electoral legitimacy and without a formal employment relationship with any institution. They are not obligated to attend the workplace daily, are not subject to labor discipline, nor accountable within the hierarchical structure characteristic of employer-employee relationships. Moreover, the compensations they receive do not constitute wages within the meaning of the Labor Law but are treated as remuneration for performing a public function. Therefore, the status of parliamentary representatives constitutes an official, but not an employment relationship. A similar legal status applies to military conscripts during their service. In their case, the element of voluntariness, which is crucial for establishing an employment relationship, is absent. Military duty arises from a statutory obligation to the state rather than the autonomous will of the subjects. For this reason, the engagement of military conscripts cannot be treated as an employment relationship but as a special legal obligation defined by public law. [6] The category of persons outside employment relationships also includes occasional, part-time, and casual performers of various tasks. These are individuals who perform duties that are not their primary occupation but are engaged occasionally, as needed, and within a predefined timeframe. Such work does not imply continuity nor formal establishment of an employment relationship and is most commonly regulated by contracts for temporary and occasional work. Furthermore, a significant number of persons outside employment relationships consist of independent professionals—lawyers, doctors, architects, journalists, artists, consultants, and others. Their professional status is based on autonomy in organizing their work and on assuming personal responsibility for the results. The work they perform is not personal in the sense of daily attendance at a workplace, nor is it subject to the client's instructions to the extent typical for employment relationships. Their engagements are contracted based on results rather than duration of work, and thus, instead of a salary, a fee or professional tariff is determined. The legal framework applicable to persons outside employment relationships is defined through multiple sources of law. The primary law indirectly regulating certain forms of such engagement is the Labor Law of the Federation of Bosnia and Herzegovina, which in Article 166 regulates the institution of contracts for temporary and occasional work. This contract allows the engagement of persons outside employment relationships, provided that the work does not exceed 60 days per year and is not considered risky under occupational safety regulations. Such persons do not enjoy all rights afforded to employees in permanent employment, especially regarding sick leave, paid vacation, severance pay, or notice periods, but are

entitled to compensation for work performed and occupational safety protection. [18] Additionally, the Law on Obligations of the Federation of Bosnia and Herzegovina regulates the legal institute of contracts for work (contract for specific work), which is a typical form of engagement for persons outside employment relationships. Under this contract, the contractor undertakes to perform a specific task or service for the client in exchange for an agreed remuneration. There is no element of daily control or hierarchical dependence, nor does the contract establish an employment relationship. The obligations arising from this contract are governed by contract law rules, whereby the parties enjoy significantly greater autonomy compared to employment contracts. Although both employment contracts and contracts for work involve providing labor for the benefit of another party, the differences between them are fundamental. The former implies a permanent legal relationship with a broader spectrum of rights and obligations, whereas the latter represents a one-time, result-oriented relationship focused on fulfilling an agreed task. In this sense, a person working under a contract for work does not acquire rights from employment law but rights stemming from a civil contractual relationship. It can be emphasized that persons outside employment relationships are an extremely important component of contemporary legal and labor systems, contributing to the functioning of the public sector, professional services, specialized tasks, and temporary assignments. However, the legal regulation of their status must be clear, consistent, and aligned with principles of fairness and respect for the dignity of work to prevent forms of concealed labor exploitation under the guise of flexible engagement.

3. Employment relationship and the status of persons outside the employment relationship in the context of rights and obligations

[1] The employment relationship has traditionally been regarded as the fundamental form of engagement through which an individual acquires the status of an employee and exercises rights related to employment. It constitutes the primary basis for defining the legal position of the worker and determining the employer's obligations, particularly regarding remuneration, occupational safety, social security, collective rights, and other related matters. Due to the need to distinguish employment relationships from other forms of engagement, [2] legal theory dedicates special attention to identifying its essential characteristics. [11] [5] The fundamental elements of an employment relationship include: the subordination relationship between the employee and employer, the personal nature of work performance, work in exchange for remuneration, and voluntary consent to work. [8] Among these elements, the element of subordination—both legal and factual—is especially emphasized. This subordination manifests in the employer's right to determine the time, place, and manner of work execution, as well as to direct and supervise the performance of tasks. The subordination relationship represents the key distinction between employment

relationships and other forms of work not governed by labor law. A person engaged outside of an employment relationship does not perform work within a hierarchy and supervision system but operates independently, determining their own working hours and methods of task execution, being responsible for the results of their work. Such work is characterized by autonomy, independence, and risk assumption, while remuneration is typically paid as a lump sum and treated as a fee or income derived from independent activity. [7] Unlike employees in employment relationships who enjoy broad protection under specific labor and social law regulations—including protection in cases of accidents, illness, maternity leave, and other circumstances—persons outside employment relationships do not automatically benefit from the same level of legal protection. Their rights depend on specific regulations governing the performance of activities, contractual obligations, as well as tax and contribution payment procedures. The current legal framework recognizes special categories of insured persons who do not fall within the classic employment relationship but are nonetheless subject to contribution obligations and entitled to certain social rights. For instance, individuals independently performing professional or craft activities, members of business entities engaged in work and receiving remuneration, and persons carrying out tasks based on contracts other than employment contracts (such as contracts for services, copyright contracts, and others) are considered insured under self-employment. This ensures the inclusion of a broader segment of the economically active population in the social security system, especially in the domain of pension and disability insurance. However, although contributions are mandatorily paid for these categories, practice shows that in some cases contributions are not linked to the acquisition of concrete rights. For example, a person paying health insurance contributions based on a contract for services, without any other basis for insurance, practically cannot access health care because there is no direct connection between contribution payment and entitlement. Similarly, contributions paid under non-standard contracts do not necessarily count towards pension service time, deepening the disparity in status between employees in employment relationships and those engaged by alternative means. [10] Recent reform proposals aim to harmonize contributions and rights by introducing unified contribution rates for persons outside employment relationships who perform remunerated work. [17] This would ensure, regardless of the engagement basis, the realization of rights to health and pension insurance under equal conditions. Such an approach strives for substantive equalization of the position of all economically active persons in terms of social security. Furthermore, taxation of income derived from independent activity or freelance professions is regulated so that such income is treated similarly to regular income from employment within the tax system. Persons earning income outside classic employment relationships are obliged to pay taxes and social security contributions, further confirming fiscal equality, even though legal protection and access to social rights remain partially limited.

4. Lawyers and notaries as specific categories of persons outside the employment relationship

The legal profession, as a form of independent professional activity in the field of legal protection, encompasses the provision of expert legal assistance, preparation of legal documents, and representation of clients before courts and other competent bodies. [15] A lawyer, as a bearer of this profession, acquires the right to practice upon fulfilling prescribed conditions, including formal registration in a professional register and a declaration of independent exercise of function. The legal profession is organized to ensure its independence, which is a fundamental prerequisite for the effective realization of the protection of clients' rights and interests. [3] The organizational structure of the legal profession includes professional chambers with mandatory membership, which supervise their members' work, adopt professional tariffs and codes of conduct, and participate in shaping the legal profession as a whole. [13] Lawyers generate income through fees and reimbursement of expenses, which are subject to taxation and contributions according to regulations governing independent professions. [4] In contrast, the notarial service represents a public function entrusted to individuals who, within a professional organization, draft and notarize legal instruments with the force of public documents. The primary role of a notary is to act impartially, protecting legality and the interests of all parties involved. Notarial activities cover family, inheritance, commercial, and property law, as well as other tasks requiring legal certainty and authenticity of documents. A common characteristic of both lawyers and notaries lies in their status as independent professionals who are not in employment relationships but operate as individuals providing services. Their work is not subject to working time schedules or other obligations arising from labor law. However, they have the right to plan their leave according to professional duties [12] and continuity of service is conditioned by responsibility towards clients and regulatory professional bodies. Obligations concerning contributions and taxes are regulated by rules applicable to independent professions. The basis for contribution calculation is income generated from professional activities, with the possibility of prescribing minimum contribution amounts regardless of income level. [16] These categories are also required to submit income reports and pay taxes based on their earnings, including personal income tax and other fiscal obligations. [14] Regarding legal liability, lawyers and notaries bear civil liability for damages caused within the scope of their professional services. This liability may arise from failure to fulfill professional duties, errors in legal advice, omissions in document preparation, and breaches of ethical and professional standards. Since they do not have employee status, these individuals cannot utilize legal protection mechanisms designed for employees in employment relationships, such as labor disputes before competent courts. Instead, they protect their interests through civil litigation before competent courts, particularly in cases of

client default, breach of contractual provisions, or infringement of their professional rights. Thus, although outside the formal employment relationship, lawyers and notaries operate within a clearly defined legal framework that determines their obligations, rights, and limits of professional autonomy.

5. Conclusion

Based on the conducted research and analysis of the legal status of lawyers and notaries as specific categories of persons outside the employment relationship, it can be concluded that these professions in Bosnia and Herzegovina represent highly specialized forms of independent professional engagement characterized by institutional independence, a high degree of professional responsibility, and specific legal regulation. Lawyers and notaries enjoy autonomy in performing their activities, yet simultaneously bear the burden of numerous statutory obligations, primarily fiscal and administrative, which often prove rigid and insufficiently adapted to the real economic conditions in which they operate. Although the legal frameworks in Bosnia and Herzegovina are designed to ensure basic social security for independent professionals, in practice the system imposes a burden on those with low or irregular incomes, as it does not differentiate between financially stable and unstable professionals. The obligation to pay contributions based on a fixed minimum base, regardless of the actual income earned, places additional financial pressure on self-employed workers, including lawyers and notaries. [9] In contrast, the legal systems of European Union member states offer a significantly more flexible approach, where contributions and other obligations are determined proportionally to actual income, with the option for voluntary additional insurance. This promotes greater inclusion in the social protection system and facilitates better balancing between professional responsibilities and the personal needs of independent workers. Particularly important is the possibility of cross-border recognition of rights and benefits, which further ensures continuity of protection regardless of changes in the place of activity within the EU. In this context, it is advisable that Bosnia and Herzegovina, in order to improve the legal and institutional framework for lawyers, notaries, and other persons outside the employment relationship, seeks in the future to align with contemporary European standards. This includes reforming the system of contribution calculation and collection, introducing greater fiscal flexibility, as well as developing mechanisms for adequate social security proportional to the actual working conditions and income levels of independent professionals. In this way, not only would the level of protection for lawyers and notaries as independent holders of legal and public functions be increased, but the development of an entrepreneurial climate in Bosnia and Herzegovina would be further stimulated through strengthening trust in the legal system and greater willingness of legal professionals to engage in independent practice, knowing that the system will provide them with appropriate institutional and social security.

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Application of artificial intelligence (AI) in telecommunications in Bosnia and Herzegovina: Opportunities of generate substantial business value

Amir Bišćević

Head of service for placement of services and support for business users, BH Telecom Joint Stock Company Sarajevo, Bihać Directorate, Bosnia and Herzegovina

E-mail: amir.biscevic@bhtelecom.ba

Abstract. Artificial intelligence (AI) is often seen as a disruptive technology because we can surely say that AI is today leading a new technological revolution, representing one of the greatest challenges in the history of humanity. It is certainly a fundamental technology for the improvement of almost all industries and societies, enabling companies and organizations around the world to complete the process of digital transformation. No matter how lagging behind in its economic and technological development, Bosnia and Herzegovina cannot avoid this influence. It should be most pronounced in the telecommunication sector, where its participants are technologically advanced companies and, by definition, should be the most prepared to apply AI in their business. This paper deals with AI and its application today in telecommunication industry in Bosnia and Herzegovina. The successful implementation of AI requires a strategic approach of the entire industry (the introduction of fifth generation of mobile networks - 5G) but also individual industry participants as well. The application of AI in the telecommunications sector offers various possibilities and opportunities. Whether it is about increasing the level of customer experience, optimizing data and maintaining infrastructure, fraud mitigation or finding new revenue opportunities, the application of AI is a 'sine qua non' if you want to achieve substantial business value and create lasting competitive advantage.

1. Introduction

In the global business environment of modern companies, there are a lot of changes that have an impact on their operations, of which technology, especially disruptive technology, has the greatest impact. Artificial intelligence (AI) is seen as such a technology that brings a technological revolution, but at the same time it represents one of the biggest challenges in the history of mankind, because the effects of the application of AI cannot be fully predicted. As an illustration, one of the more vivid confirmations is

the selection of the best slogan from the graduation ceremony in Croatia this year.: "We passed the FIRST year, the other three ChatGPT." [1]

In Bosnian-Herzegovinian society, there is a lot of mention of AI and the possibilities of its application, but as in most matters concerning economic and technological development, Bosnia and Herzegovina lags behind developed countries. Nevertheless, the leaders of the effective application of AI, by definition, are companies from the telecommunications industry whose key activity should be the completion of the started process of digital transformation of the Bosnian-Herzegovinian society.

At the declarative level, this has been recognized by the leading telecommunication companies. So BH Telecom d.d. Sarajevo has a mission to connect and develop Bosnia and Herzegovina through innovative digital solutions. [2] Motto of HT d.d. Mostar is that they are a digital company for the digital age [3] and Telecom Srpske a.d. Banjaluka wants to be a recognized global actor in the digital world. [4] It is questionable how achievable this is if we know that Bosnia and Herzegovina have not yet introduced the fifth generation of mobile network (5G), as one of the basic prerequisites for the effective application of AI, and there is no official information when it is planned to do so.

The application of AI in the telecommunications sector offers various possibilities and opportunities. In the continuation of this paper, we will explore what can be done specifically in this matter.

2. Current state of the telecommunications industry in Bosnia and Herzegovina

The telecommunications industry has been one of the most attractive industries for a long time and thanks to its role in providing internet and mobile connection services, it has experienced higher periods of revenue-growth cycles. Today, the situation is quite different because we can say that the telecom industry is growing, but slowly. This growth is lower than the projected inflation rate. According to PwC's Perspectives from the Global Telecom Outlook 2024-2028, it is predicted that until 2028, global revenues of the telecommunications sector will grow at a compound annual rate (CAGR) of only 2.9 %. [5] The trend that is present in the telecommunications industry is that their services are becoming more and more commoditized, that is, the differences between the services of individual competitors on the market are decreasing, which makes users more sensitive to prices. This reduces the space for telecoms to raise the prices of their services. On the other hand, the costs of investment in 5G infrastructure have been reduced rapidly, and the introduction of 6G is not expected before 2030.

The state of the telecommunications market in Bosnia and Herzegovina does not follows these trends. First, as it was said in the introduction, 5G has not been implemented, which means that once it is established (and it will have to be), it will require significant investments. On the other hand, telecommunication services in Bosnia and Herzegovina, due to the very characteristics of the market and the existence

of "national" telecoms, are not yet commoditized and therefore still leave space for telecoms to increase service prices. Telecom companies are using this possibility, where according to the available financial data, there has been an increase in the income of the dominant telecom operators (Figure 1.). [6] But a comparison of number of users and subscribers and outgoing traffic including send SMS - MMS shows that the entire telecom industry is stagnating (Table 1.). [7]

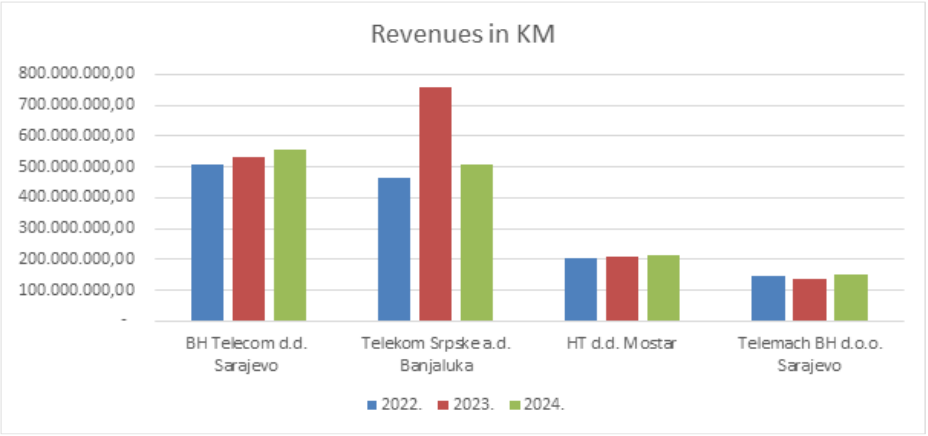

Figure 7. Revenues of dominant Telecom providers in Bosnia and Herzegovina (note: anomaly in the revenues of Telecom Srpska in 2023 is due to the sale of tower infrastructure).

3. The development of Artificial Intelligence and the emergence of Generative Artificial Intelligence

There is a lot of discussion about AI and its benefits, but also possible negative consequences in its use, and the fact that the EU has officially adopted the AI Act, which regulates this sphere, confirms how seriously it is approached. [8] In Article 3 of this Act is also given the definition of AI: AI system means a machine-based system that is designed to operate with varying levels of autonomy and that may exhibit adaptiveness after deployment, and that, for explicit or implicit objectives, infers, from the input it receives, how to generate outputs such as predictions, content, recommendations, or decisions that can influence physical or virtual environments. [9] Inside that system, Machine Learning (ML) focuses on developing algorithms that allow computers to learn from data and improve performance over time without the need for explicit programming. Deep Learning (DL), a subset of ML, uses deep neural networks to create complex data, enabling advances in areas such as image recognition and automated translation.

Generative Artificial Intelligence (GenAI) refers to a class of AI models that create new content, such as text, images, audio, and video, based on existing data. Using advanced deep learning techniques GenAI applications can produce human-like responses, realistic visuals, and creative compositions. The launch of ChatGPT-3.5 at the end of 2022 captured the world's attention and illustrated the uncanny ability of GenAI

to produce a range of seemingly human-generated content, including text, video, audio, images, and code. Closely related to ChatGPT is the concept of Large Language Models (LLM), which is the most widespread type of AI today and is used by most companies. However, these models require a lot of preliminary work, require significant investment, and still do not provide completely reliable results. That's why many companies are now turning to so-called Small Language Models (SLM) that can solve specific problems instead of some general queries.

Table 3. Telecommunication services in Bosnia and Herzegovina.

Year	2024	*2023*	2022	*2021*	2020
Total number of fixed telephone lines of incumbent operators	443.613	472.720	505.128	543.117	559.986
Outgoing total traffic fixed	201.777.900	238.350.668	273.722.198	341.775.603	422.653.219
Total number of mobile network users	3.836.099	3.874.277	3.811.931	3.728.775	3.509.674
Total outgoing traffic of mobile operators (in minutes)	661.282.651	646.624.422	656.444.264	681.131.665	660.948.314
SMS sent	57.719.122	68.743.356	70.386.724	87.761.023	91.495.834
MMS sent	239.537	340.903	325.649	305.716	307.781

A greater level of specialization and a series of smaller models working side by side is the most likely direction of AI development. The trend we're talking about is called Agentic AI, which could dominate the next decade, in which machines use sophisticated thinking and planning in stages, in the same way that human workers do, which existing AI models still can't. What Agentic AI is expected to do is take over repetitive and trivial tasks, searching for information and resources using data that companies have, which has been found to be more valuable than previously thought. In the coming years, AI could and should focus on completing tasks instead of improving human work.

To conclude, AI is a new paradigm that will certainly take the world to a new level, just as the appearance of the internet did thirty years ago, or applications twenty years ago. There will be an exponential growth in the use of AI tools. That is why most companies will increasingly use AI, but it is important to find the right application and the problems that can be solved with it, which will ultimately make work easier.

4. Applying AI in telecom industry: Possibilities and benefits

Modern businesses benefit from AI in industry operations in a variety of ways, with global leaders expecting it to take over 30% of their tasks within the next few years. [10]

The possibility of applying AI exists in almost every industry, and the telecom industry is at the very top. For example, according to some research, it is in fourth place in terms of potential increase in operating profit margin (13%). [11] That is why 97% of telecoms are adopting AI. [12] Main benefits of AI in telecom industry are shown in the following Figure 2.

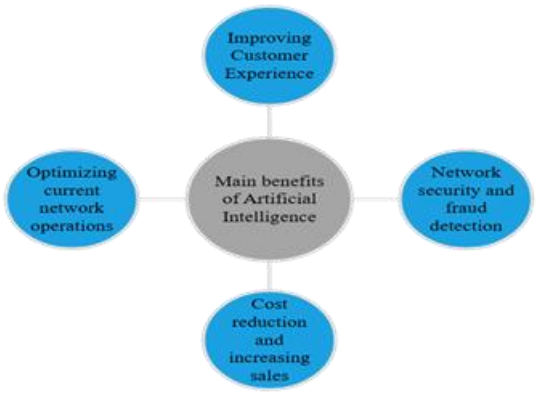

Figure 8. Main benefits of AI.

A large number of innovations in information technology have significantly increased customer expectations. Today, they demand fast, seamless and personalized service with high bandwidth speeds and no interruptions. On the other hand, the traditional model of customer service is based on reaction, because it is the user who initiates contact and communication, most often because of a problem they have. This puts the telecom company in an unfavourable situation because the user is already dissatisfied and if this problem is not solved efficiently, there may be an escalation of frustration and anger with the consequence of changing the service provider. This is one of the main reasons that only one in three customers stay with their service provider for over five years. [13] The use of AI should fundamentally change that approach, from reactive to proactive customer care. AI eliminates frustrating wait times and automates complex support tasks. Powered by GenAI capabilities, this transformation is driven by AI's ability to anticipate customer needs, enable instant solutions, automate routine tasks and deliver personalized service in real time. AI enables predictive analytics through which it analyses user behaviour, their past interactions and real-time data to identify a potential problem, thus ensuring that the service is consistent and relevant to their real needs. And not only that, GenAI enables the creation of highly personalized marketing campaigns and customer journeys powered by predictive models than anticipate individual behaviour. [14] Sales teams will be able to identify sales opportunities for upsell and cross-sell (for example, to those customers who are willing to pay more for superior network quality, low latency, high security, etc.). This increases revenue and at the same time increases the level of Customer Experience. Of course, AI

cannot completely replace human support and empathy that such interaction provides. A synergy between these two approaches is needed.

The impact of AI on network operations is closely tied to the user and their experience. AI-driven predictive maintenance will be able to detect network problems, anomalies and equipment failures before they actually occur, reducing downtime and ensuring uninterrupted connectivity. Furthermore, AI will be able to provide precise data and guidance for future investments by telecoms in network infrastructure, where the highest and fastest returns will be achieved and where the highest quality service will be provided to users with the greatest sales potential. The ultimate goal is self-healing networks, meaning autonomous in identifying and resolving network problems with little or no human intervention. These activities offer significant opportunities for reducing costs while increasing network reliability.

A significant application of AI is also in traffic flow optimization. In this way, it can successfully recognize and respond to unforeseen traffic surges by managing temporary capacity to prevent customer frustration. On the other hand, the intelligent monitoring network in the Radio Access Network (RAN) in the case of low traffic switches to low-power operation mode or even turns it off, which results in significant energy savings because 87% of energy is consumed in the RAN. [15] Also, AI is applied to the maintenance segment of mobile towers, where it will be used to recognize anomalies in the operation of the towers, security incidents or alarms.

AI-driven security frameworks provide real-time monitoring ensuring that telecoms remain resilient to fraud and cyber-attacks and threats that, paradoxically, are becoming more numerous and dangerous thanks to the development of AI. The goal of applying AI is to identify and stop threats before they cause harm. Predictive analytics are used to prioritize threats, reducing response time. Disaster recovery plans are created and implemented to safeguard sensitive information and eliminate exposure and vulnerability. This allows you to minimize financial losses, avoid loss of reputation and keep legal and regulatory compliance.

5. Current use of AI in the telecom industry in Bosnia and Herzegovina and guidelines for greater and better application of AI

In the previous chapter, we listed only the most important possibilities of applying AI in the telecom industry. This is certainly recognized by global telecoms, and as a confirmation of this, their management is planning a much larger investment in the development and application of AI than has been the case so far. According to some recent research, almost two-thirds of them put aside dedicated funding for AI in their budgeting. [16]

What is the situation in the telecom industry in Bosnia and Herzegovina and the application of AI? Three of the four dominant telecom operators have applied AI in the domain of ChatBots or Virtual Assistants to support customers, but this is still at the

very beginning of application. Much larger investments are needed to realize the benefits of applying AI to increase the level of Customer Experience. Telecom operators do not communicate to the public and stakeholders their intentions to invest in AI, but knowing that the activities of implementation 5G have been reduced to a minimum, it is assumed that no larger investments are planned for the next period. This year, BH Telecom started some preparatory activities by implementing OmniChannel support in its sales channels, where the sales staff is obliged to enter all interactions with their customers. This will create a high-quality database that AI will be able to successfully process and predict activities that will contribute to increasing the Customer Experience.

Most of the fixed infrastructure is still copper, although optical infrastructure is being built, but not fast enough. Because of this, the quality of the service provided to customers is low, and the consequence is a large number of reported incidents. This problem is often repeated several times, which ultimately leads to an escalation of frustration of customers, which results in lost income. In the segment of mobile infrastructure, there is currently little that can be done since 5G has not been introduced.

Therefore, below we will provide a guide for greater and better application of AI in the telecom industry in Bosnia and Herzegovina:

1. Intensify activities towards regulators to accelerate the introduction of 5G
2. Include the full application of AI in business in their strategic goals
3. Significantly increase budgets for the application of AI
4. Expand the application of AI to all areas of business, from increasing the level of Customer Experience, through maintaining and optimizing network and increasing information security to identifying sales opportunities to increase revenue.

6. Conclusion

There are many benefits of using AI in company operations, especially in the telecommunications industry. By adopting advanced AI technologies, telecoms will be able to effectively manage the network infrastructure, which will simultaneously increase the level of Customer Experience and reduce costs, but not only that. With a personalized approach to each user, it is possible to unlock new sources of income, which will ensure long-term success. In order to use the full potential provided by the application of AI, telecoms in Bosnia and Herzegovina must first of all fully accept AI technology, incorporate it into their strategies and allocate significant funds for its implementation in the next period. With this, Telecoms will take the lead in shaping the future of Bosnian-Herzegovinian digital society.

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Perception and understanding of patient rights in the healthcare system

Lejla Hodžić[1], Nermina Kurtalić[2], Sadat Kurtalić[2] and Sena Našić[1]

[1]University of Bihac, Faculty of Health Studies, Bosna and Hercegovina
[2]Cantonal Hospital "Dr. Irfan Ljubijankić", Bosna and Hercegovina

E-mail: lejlaaa1901@gmail.com

Abstract. Patient rights represent a crucial aspect of healthcare, ensuring their awareness, autonomy, and dignity throughout the treatment process. Patient rights, including the right to information, informed consent, privacy, and quality healthcare, are essential for ethical medical service provision and patient satisfaction. The aim of this study is to assess the level of patient awareness regarding their rights in the healthcare system and to analyze their perception of communication with medical staff and access to legal protection measures. The study included participants who had been hospitalized in one of the departments of the Cantonal Hospital "Dr. Irfan Ljubijankić" in Bihać. Data were collected through a pre-prepared questionnaire, and the analysis was conducted using descriptive statistical methods. The results indicate that most patients are familiar with their basic rights, but 24% are not aware of them. Regarding communication with medical staff, 68% of respondents rated it positively, while 32% expressed dissatisfaction. The majority of patients were examined on time and felt that they received adequate attention during their examinations. However, 52% of respondents believe that the hospital is not adequately equipped in terms of infrastructure. In the event of a rights violation, most respondents would turn to medical staff, while only a small percentage would seek legal assistance. A comprehensive analysis has determined the need for better patient education about their rights, improved communication between patients and medical staff, and enhancements in healthcare infrastructure. These improvements would ensure higher quality services and greater trust in the healthcare system. Various types of training and additional education for medical staff should be a priority to foster greater empathy and understanding of patient needs.

1. Introduction

Patients' rights form the foundation of an ethical and lawful healthcare system, safeguarding the integrity, autonomy, and dignity of every individual. These rights include the right to information, free and informed consent, privacy, data confidentiality, safety, and active participation in decisions regarding one's own treatment [1,2]. At the international level, the framework for patient protection is established by the European Charter of Patients' Rights [1] and the Convention on Human Rights and Biomedicine

(Oviedo Convention) [2], both of which emphasize the obligation of states to provide legal and institutional protection of health-related rights.

In the legislation of the Federation of Bosnia and Herzegovina, these rights are addressed in several legal documents. The Law on the Rights, Duties and Responsibilities of Patients of the Federation of BiH outlines key principles, including the right to information, choice, and consent [3]. The Law on Health Protection defines the organization of the healthcare system with a focus on accessibility, equality, and respect for human rights [4], while the Law on the Protection of Personal Data ensures the confidentiality of patients' medical information [5].

However, the mere existence of laws and charters is not sufficient—their practical application depends on institutional procedures, the education of healthcare professionals, and the level of awareness among patients themselves [6]. In practice, many patients remain inadequately informed about their rights, particularly within public healthcare institutions. A study conducted in Palestine revealed that only 47% of patients had adequate awareness of their rights [7], while in Sudan, that figure was as low as 4.6% [8]. Similarly, in Saudi Arabia, more than half of the respondents were unaware of basic rights such as the right to information and consent [9].

In such a context, healthcare institution accreditation has been recognized as a tool that helps hospitals transform legal rights into practical procedures and improve implementation through process standardization [6]. Nevertheless, even in countries with well-developed legislation, such as Croatia, it has been shown that mechanisms for protecting patients' rights are often inefficient, uncoordinated, and not easily accessible to patients [10].

Given the importance of patients' rights for the quality of healthcare and the lack of research in this area in Bosnia and Herzegovina, the aim of this study was to examine the level of patient awareness at the Cantonal Hospital "Dr. Irfan Ljubijankić" in Bihać regarding their rights, the quality of communication with healthcare staff, and their willingness to seek protection in the event of a rights violation.

2. Participants and methods

A study was conducted among patients who were hospitalized at the Cantonal Hospital "Dr. Irfan Ljubijankić" in Bihać. To ensure the representativeness of the sample, the research was carried out among patients hospitalized in various departments. The sample also included patients from different age groups and with different levels of education.

The participants were selected randomly, and data collection took place over a three-month period. The study was designed to allow respondents to express their awareness of patients' rights, the quality of communication with healthcare staff, and their overall satisfaction with the healthcare services provided.

The methodological approach included a questionnaire consisting of pre-formulated questions. These questions addressed various aspects of patients' rights, such as the level of awareness, experiences in communication with healthcare staff, and perception of the quality of the provided healthcare services. The questions were structured to allow for simple and clear responses.

Descriptive statistics were used to analyze the collected data in order to provide an overview of the basic characteristics of the participants. This method allowed for the identification and summarization of key demographic information, such as the age and education level of the respondents.

The data were presented through frequency distributions, which showed the distribution of respondents by age groups (under 16 years, 16–20 years, 21–40 years, 41–60 years, and over 60 years) and by educational level (lower secondary education, secondary education, and higher or university education).

This analysis enabled a clear understanding of the structural characteristics of the sample. In addition, percentage values were used to illustrate key findings, such as the proportion of respondents who reported being aware of their patient rights or those who were satisfied with the quality of communication with healthcare staff. Descriptive statistics provided the basis for further analysis and interpretation of the results, allowing for a clearer insight into the research findings.

3. Results

The study included a total of 100 participants who constituted the research sample. Among them, 90 (90%) were patients themselves, while 10 (10%) were parents of patients. The average age of participants was 47 years. Regarding age distribution, the largest group consisted of individuals aged 41–60 years (63%), followed by those aged 21–40 years (17%), over 60 years (15%), 16–20 years (4%), and under 16 years (1%).

With respect to education level, 52 participants (52%) had completed secondary education, 28 (28%) had higher or university education, and 20 (20%) had lower vocational education.

Table 1. Demographic characteristics of respondents

Category	Response	% / Number of Patients
Role of respondent	Patients themselves	90%
	Parents/Guardans	10%
Age distribution	41–60 years	63%
	21–40 years	17%

	Over 60 years	15%
	16–20 years	4%
	Under 16 years	1%
Education level	Secondary education	52%
	Higher/university education	28%
	Lower vocational education	20%

According to their experience, 80 participants (80%) reported that their appointments were conducted at the scheduled time, while 20 (20%) said they were not. Furthermore, 76 participants (76%) felt that medical staff allocated sufficient time for their examination, whereas 24 (24%) did not share that opinion. When it came to receiving information about their illness, 69 participants (69%) confirmed they were adequately informed, while 31 (31%) were not.

The majority of participants (69%) also stated that healthcare staff treated them with kindness and professionalism, in contrast to 31% who felt otherwise. Additionally, 79% of participants felt that their privacy was respected during the provision of healthcare services, while 21% believed it was not.

Regarding patient involvement in decision-making about their treatment, 76% of respondents confirmed they were involved, while 24% were not. In line with this, 79% said that healthcare personnel respected their decisions and wishes regarding treatment, whereas 21% did not feel that their preferences were honored. In terms of informed consent, 90% of participants confirmed that they provided informed consent prior to treatment or procedures, while 10% reported that they had not.

When asked about the adequacy of healthcare facility equipment and conditions, opinions were split: 48% of participants believed the institution was adequately equipped and maintained, whereas 52% disagreed. Notably, 77% of participants stated that they would seek legal protection in the event of a medical error, while 23% would not pursue such action.

Participants were also asked to identify specific patient rights they were familiar with (multiple answers allowed). The most recognized right was the right to information (80%), followed by the right to a second opinion (74%), the right to dignified treatment (73%), data confidentiality (64%), the right to free consent (62%), and the right to file complaints (60%). Nevertheless, 24 participants (24%) reported that they were not familiar with any patient rights.

When asked whom they would contact in the case of a violation of their rights, 30% of respondents said they would first turn to a nurse, 28% to their physician, 17% to the hospital director, 12% to a lawyer, 5% to the judiciary, 4% to the media, and 2% stated that they would not report the violation to anyone.

Table 2. Awareness and understanding of patients' rights

Category	Response	% / Number of Patients
Awareness of patients' rights	Aware	72%
	Not aware	28%
Most known rights	Right to information	80%
	Right to a second opinion	74%
	Dignified treatment	73%
	Data confidentiality	64%
	Free consent	62%
	Right to file a complaint	60%
Willingness to seek legal protection	Yes	77%
	No	23%
Whom they would contact	Nurse	30%
	Doctor	28%
	Hospital director	17%
	Lawyer	12%
	Judiciary	5%
	Media	4%
	No one	2%

Table 3. Perception of healthcare quality and communication

Category	Response	% / Number of Patients
Communication with staff	Positive	68%
	Negative	32%
Information about ilness	Received	69%
	Not received	31%
Participation in decision-making	Yes	76%
	No	24%
Informed consent	Given	90%
	Not given	10%
Staff courtesy	Yes	69%
	No	31%
Respect for privacy	Yes	79%
	No	21%
Timeliness of examination	On time	80%
	Not on time	20%
Sufficient time for examination	Yes	76%
	No	24%
Satisfaction with infrastructure	Satisfied	48%
	Not satisfied	52%
Respect for patient wishes and decisions	Yes	79%
	No	21%

4. Discussion

The results of the research conducted at the Cantonal Hospital "Dr. Irfan Ljubijankić" show that 72% of patients are aware of their rights, while 28% are not. Compared to a study conducted in Sudan, where only 4.6% of respondents were aware of the existence of a patients' rights charter [8], the findings from Bihać indicate a significantly higher level of awareness. Nevertheless, the fact that over a quarter of patients are uninformed highlights the need for further education, especially considering that the right to information is a fundamental human and healthcare right [1,3].

Similar to the study in Palestine, where the majority of patients were aware of their right to dignified treatment (92.8%), privacy (82%), and non-discrimination (81.5%) [7], this study also found that the highest number of patients recognized the right to information (80%), the right to a second opinion (74%), and the right to dignity (73%). However, rights such as confidentiality, the right to complaint, and free consent were less frequently identified, which is consistent with findings from Saudi Arabia, where 55.1% of patients were unaware of their right to be informed about treatment risks, and 64.8% did not know they could appoint a healthcare proxy [9].

At the Cantonal Hospital "Dr. Irfan Ljubijankić," 90% of patients reported giving informed consent, and 76% participated in treatment decision-making. This represents a higher level of engagement compared to findings from Pakistan, where only 30% of patients were aware of their right to all necessary information before providing consent [11]. Still, the fact that 10% of patients did not provide consent and 24% did not participate in decision-making raises concerns about inconsistent practices and the need for additional training of medical staff [6].

Communication remains a critical issue—68% of patients reported being satisfied with communication with medical personnel. Although this is higher than in many developing countries, it still shows that nearly one-third (32%) of patients had a negative experience, which can impact trust and the overall quality of care [9,11].

As seen in Croatia, where the system for reporting violations of patients' rights is fragmented and uncoordinated [10], this study also found that most patients would not seek formal legal assistance in the case of rights violations. Only 5% of participants stated they would turn to judicial authorities, while the majority would attempt to resolve the issue internally. This suggests low legal literacy and a weak institutional response.

Furthermore, more than half of the participants (52%) believe that the hospital is not adequately equipped in terms of infrastructure. This may directly affect not only the perception of care quality but also the actual ability to exercise certain rights, such as privacy, dignity, and safety [6].

5. Conclusion

The study conducted among hospitalized patients at the Cantonal Hospital "Dr. Irfan Ljubijankić" provides insight into the current state of awareness and realization of patients' rights. Although the majority of patients consider themselves generally informed about their rights, a significant portion remains insufficiently aware, highlighting a clear need for continuous and comprehensive education—both for patients and healthcare professionals.

Positive findings of the study include a high level of patient involvement in decision-making processes, the provision of informed consent, and the protection of privacy. These results suggest that the foundation for respecting patients' rights has been established. However, there are still areas in need of improvement. While most patients expressed satisfaction with communication with medical staff, a considerable number still lack complete information, which may hinder their ability to make fully informed choices.

One of the more concerning findings relates to the low willingness of patients to use formal legal mechanisms in cases where their rights have been violated. This points to a deeply rooted distrust in institutions, as well as insufficient knowledge about available legal tools and procedures for protecting patients' rights. Additionally, the perception of inadequate hospital equipment emphasizes the need for further investment in healthcare infrastructure to ensure an appropriate level of services and protection for all patients.

To further improve the level of protection of patients' rights and strengthen trust in the healthcare system, several key steps must be taken. First, implementing continuous education programs for both patients and healthcare professionals should become a priority, as systematic dissemination of information is essential for ensuring active and responsible patient participation in the treatment process. Second, enhancing the communication skills of medical staff is crucial to ensure clear, transparent, and empathetic dialogue, enabling patients to fully understand their options and rights. It is also important to establish clear mechanisms for lodging and resolving complaints, so that patients feel safe and supported in cases of rights violations. Finally, investing in healthcare infrastructure is a key factor in ensuring the quality of healthcare services and adequate conditions for patients.

By implementing these recommendations, multiple benefits can be achieved: increased respect for patients' rights, strengthened trust in the healthcare system, and overall improvement in the quality of care. This comprehensive approach will ensure a better patient experience, allowing individuals to feel safe, respected, and fully informed about their treatment.

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Managing EU funds in Bosnia and Herzegovina: financial and legal instruments

Alma Džanić

University of Bihac, Faculty of law, Bosnia and Herzegovina

E-mail: alma.dzanic@unbi.ba

Abstract. The European Union (EU) funds for Bosnia and Herzegovina (B&H) represent the key investments that brings B&H closer to the EU standards in all aspects. This paper emphasizes the EU's comprehensive approach in managing funds in B&H, which integrates the financial and legal instruments creating better opportunities and enables the economic, social and political reforms and development. The aim of this paper is to analyse and present the financial and legal instruments, access and availability, purpose and type of support in managing EU funds and programs for Bosnia and Herzegovina. The purpose of managing EU funds in B&H is reflected, not only, in an inevitable way to assist beneficiaries in implementing political and economic reforms, but also in preparing for the rights and obligations that come with EU membership.

1. Introduction

The EU funds support cooperation between member countries and their citizens in different EU policy areas. Although these funds are intended to member states, the European Union offered to potential candidates and candidates' countries, and thus to Bosnia and Herzegovina the opportunity to participate in funding programs, with prior implementation of the prescribed procedures and fulfilling the necessary prerequisites, in order to supported their accession to the European Union. [1]

Through the EU funds it has been providing an opportunity for different organizations, institutions and individuals to get involved in the activities through partnerships with European colleagues and in that way review EU policies, standards, processes and methods of work, and gain new knowledge and experience. Therefore, the EU funds are powerful tool not only for supporting the accession process but also a way to include as much as possible actors in that process. [1]

2. The EU funds

The EU funds are public resources of the taxpayers of the European Union and are part of the joint budget of all member states and therefore important both because of their value and because of the strategic goals that are achieved through financial

instruments. [2] The EU provides funding for a range of projects and programmes. It applies strict rules, for tight control over how funds are used and to ensure money is spent in a transparent, accountable manner. [3]

2.1 Types and management of EU funding

EU funding comes in many different forms: [3]

- grants – typically, people apply for grants by submitting ideas for projects following a "call for proposals";
- subsidies managed by national or regional authorities;
- loans, guarantees and equity as forms of financial assistance to support EU policies and programmes;
- loans to EU Member States and non-EU countries;
- prizes for winners of Horizon Europe contests.

Programmes funded by the EU budget can be managed in three different ways: [3]

- direct management: EU funding is managed directly by the European Commission;
- shared management: the European Commission and national authorities jointly manage the funding;
- indirect management: funding is managed by partner organisations or other authorities inside or outside the EU.

European institutions publish tenders and invite candidates to propose, within a certain period, an action or a project that corresponds to certain goals and meets the necessary conditions. Financial support can be granted in various areas such as research, education, health, consumer protection, environmental protection, humanitarian aid, etc., and are intended for various types of organizations such as small and medium enterprises, agencies and chambers, education and research centers, financial institutions, public administration, civil society organizations, companies, schools, universities, etc. The EU funds apply on more than thirty areas: civil society, economy and finance, energy, citizenship, humanitarian aid, information, industry, innovation, research, public management, culture, media, art, local development, human rights, youth, new technologies, education and training, environment, small and medium-sized enterprises, agriculture and fisheries, justice and security, transport, EU enlargement, social issues, cooperation and development, telecommunications, trade, tourism, services, urban planning, employment, health and others. [4]

2.2 Access to EU funds and programs

The aim of EU funds and programs are providing support for policies and priorities of European Union through the improvement of cooperation between member states and their citizens in different areas. [5] According to the current EU long-term budget covering period 2021–2027 (Multiannual Financial Framework), financial resources are divided into three parts: cohesion policy, the common agricultural policy and the new enhanced priorities. [6]

The possibility of participating in EU programs was opened to the countries of the Western Balkans by the conclusions of the European Council in Thessaloniki from June 2003, with the aim of supporting efforts on the way to European integration, with the exchange of good practices, experiences and knowledge. The participation of the countries of the Western Balkans in EU programs is regulated by framework agreements on the general principles of the participation of individual countries in EU programs. With the entry into force of the Framework Agreement on the General Principles for the Participation of Bosnia and Herzegovina in Community Programs, from January 2007, Bosnia and Herzegovina gained the possibility of joining individual programs. Candidate countries and potential candidates for EU membership are recommended to selectively and gradually access these programs in accordance with their own needs, capacities, strategic interests and expected benefits. The process of joining the program is initiated for each program separately, and the bearer of activities related to joining is the competent institution at the state level. In order for a country to join a particular program, it is necessary to conclude an international agreement with the European Union and pay a financial contribution for participation in the program (the so-called entry ticket) for each year of participation in the program. Participation in EU programs is achieved by publishing calls for submission of project proposals and awarding financial support to selected projects. Projects supported as part of the EU program usually require the participation of partners from several member states of the program, as well as co-financing of projects from the applicants of project proposals. [5]

It should be emphasized that EU funds are not allocated without conducting a specific public call for EU external aid actions. These procedures are initiated by the Delegation of EU in Bosnia and Herzegovina or at the level of the EU services in Brussels and in the appropriate form like:

- procurement of services;
- call for proposals/grants;
- procurement of goods or works;
- twinning agreement (refers to assistance from the public administrations of EU member states to potential "twins" in the B&H public administration, i.e. similar segments of the administration such as, for example, a certain ministry or agency).

Call for fundings for the above-mentioned forms of procurement are published on the website of the Delegation of the European Union under the section Tenders of the EU Delegation and on the website of Europe Aid. [3], [5]

3. The EU funds for Bosnia and Herzegovina

As already stated, certain funds and resources are intended for countries that are not members of the European Union. Funds and programs for non-member countries fall under the budget chapter of the EU as a global partner, and in fact they are aid and cooperation programs

Previously, due to its status on the European path, Bosnia and Herzegovina did not have access to all aid programs offered by the EU. As a potential candidate B&H had two types of assistance available: [5]

- assistance in the transition and development of institutions - intended for the development of capacities and institutions; and
- cross-border cooperation – intended to provide assistance in the area of cross-border cooperation between current member states and candidate and potential candidate countries, and cooperation between candidate and potential candidate countries.

Since 1995, the EU has allocated more than 3 billion of euros in aid. These funds were paid for the immediate and strategic needs of the citizens of B&H: [5]

- In the period of 1995 to 2000, the emphasis was on humanitarian aid, the return of refugees and the restoration of physical infrastructure.
- After that, EU funds were directed towards the establishment and development of institutions, and political and economic systems that help Bosnia and Herzegovina become a fully functional state.
- After the signing of the Stabilization and Association Agreement in June 2008, EU funds were directed primarily through the Instrument of Pre-Accession Assistance (IPA) to help Bosnia and Herzegovina adapt its economic, political, security and social system as the requirements of future EU membership.

The EU aid and funds are always provided in accordance with a comprehensive strategy that is aligned with the circumstances of the development of the country. In addition, the EU funds are almost always linked to projects that bring concrete and visible improvements and benefits in the everyday lives of B&H citizens.

Currently, B&H has access to the following financial instruments: [5]

- Instrument for Pre-Accession Assistance (IPA);
- Transnational cooperation;
- Western Balkans Investment Framework (WBIF);
- The EU Programs;
- Macro-Regional Strategies;
- Technical Assistance and Information Exchange (TAIEX)

3.1 Instrument for Pre-Accession Assistance (IPA)

The Instrument for Pre-Accession Assistance (IPA) is the main financial instrument of the European Union to assist beneficiary countries in progressive alignment with the standards and policies of the EU, including the acquis, aimed at accession to the EU. The IPA represents a comprehensive support to the process of European integration, through financial, technical and expert support to the reforms. In 2006, in order to support candidate countries and potential candidate countries, the European Union brought together all the forms of support (CARDS, SAPARD, ISPA, PHARE, instrument for Turkey) into one Instrument for Pre-accession Assistance (IPA). The IPA funds are intended primarily for the institutions to assume their obligations, but they are also

available to other beneficiaries (non-governmental organisations, business community, border regions, local self-government units, agricultural holdings and other natural persons or legal entities). [7] The IPA program as an integrated pre-accession fund of the European Union is established by the Council of Europe Regulation no. 1085/2006. [8]

The IPA I (2007-2013) was implemented within five components: [7]

- IPA component 1 – Assistance for transition and institution building;
- IPA component 2 – Cross-border cooperation;
- IPA component 3 – Regional development;
- IPA component 4 – Human resources development;
- IPA component 5 – Agriculture and Rural development.

Within the IPA I, as a potential candidate for EU membership, B&H could benefit from the first two components (Assistance in institution building and Cross-border cooperation) while the remaining three components were available only to the candidate countries.

For the period 2014-2020, the European Commission made certain revisions and introduced the Instrument for Pre-Accession Assistance IPA II. In order to establish the Instrument for Pre-Accession Assistance (IPA II), as well as to define the objectives, specific rules, general provisions and procedures for the implementation of this programme, the European Parliament and the European Commission have adopted a set of legal acts necessary for the programme implementation. On 11 March 2014, the European Parliament and the Council adopted the Regulation No 231/2014 establishing the Instrument for Pre-accession Assistance 2014-2020 (IPA II). The regulation stipulates that the general objective of the IPA II is to support beneficiary countries in the process of adopting and implementing political, legal, administrative, social and economic reforms in order to comply with the EU rules and values. Hence, IPA II is implemented in five policy areas: [9]

- Reforms in preparation for Union membership and related institution and capacity-building;
- Socio-economic and regional development;
- Employment, social policies, education, promotion of gender equality, and human resources development;
- Agriculture and rural development;
- Regional and territorial cooperation.

Financial assistance was available to beneficiary countries in all the policy areas, regardless whether the country had a status of a candidate or a potential candidate.

The Regulation of the European Parliament and of the Council No 236/2014 of 11 March 2014 defined the rules and procedure for the implementation of the Instrument for Pre-Accession Assistance for the period 2014–2020, such as: management and control rules for programming and implementation of assistance, and rules for financial management.

The main difference in relation to the instrument for pre-accession assistance I was introduction of a sector approach in planning of the use of funds, enabling targeted

assistance, ensuring efficiency, sustainability and focus on results. Sectors for IPA II support are jointly identified by the EU and the beneficiary countries, based on the set criteria: [9]

- Well defined government sector policies/strategies;
- Institutional setting, management and capacities for the sector strategy implementation;
- Sector and donor coordination;
- Medium term budgetary perspectives for the implementation of sector policies;
- Monitoring of the implementation of sector policies and evaluation of achievements;
- Public Financial Management (efficient, effective and transparent) and agreements on sector budget;
- Present and projected (planned) macroeconomic framework, within which sector policies would be implemented.

The Framework Agreement on IPA II between Bosnia and Herzegovina and the European Commission entered into force on 24 August 2015. Sectors of the Instrument for Pre-Accession Assistance II for Bosnia and Herzegovina were included in the Indicative Strategic Document (2014-2017) and were as follows: [10]

- Democracy and governance;
- Rule of law and fundamental rights;
- Competitiveness and innovation: local development strategies;
- Education, employment and social policies.

In addition to the existing sectors, and the sector of Transport, which qualified for the IPA II support in 2016, the Revised Indicative Strategy Paper for Bosnia and Herzegovina for the period 2014 - 2020, included the new sectors: [10]

- Agriculture and rural development;
- Environment and energy.

Regulation (EU) 2021/1529 of the European Parliament and of the Council of 15 September 2021 establishing the Instrument for Pre-Accession Assistance (IPA III) continues to financially support legal, economic and social reforms in candidate and potential candidate countries, enabling them to meet the criteria for the EU membership. Commission Implementing Decision of 10 December 2021 adopting the Instrument for Pre-Accession Assistance (IPA III) Programming Framework for the period 2021-2027. Unlike the previous two, the third generation of Instrument for Pre-Accession Assistance, abandons the principle of indicative financial allocations by country and replaces it with the principle of indicative financial allocations by windows. These five thematic windows represent the objectives of the EU enlargement policy. Each window contains a number of designated thematic priorities that are exclusive to each of the IPA III beneficiary countries, and reflect various aspects of the EU acquis and policies: [11]

- Window 1: Rule of law, fundamental rights and democracy;

- Window 2: Good governance, EU acquis alignment, good neighbourly relations and strategic communication;
- Window 3: Green agenda and sustainable connectivity;
- Window 4: Competitiveness and inclusive growth;
- Window 5: Territorial and cross-border cooperation.

The proportion of indicative amounts channelled to individual IPA III beneficiary countries depends on their progress in reforms implementation, particularly fundamental ones in the fields of the rule of law, public administration reform, and sustainable economic development and competitiveness. The third generation Instrument for Pre-Accession Assistance upgraded the management process overseeing the following: financial framework partnership agreement, planning and programming, programming framework, strategic response, action fishe etc. according to the EU Regulation 2021/2236. [12]

Financial framework partnership agreement between the European Commission and Bosnia and Herzegovina on specific arrangements for implementation of Union financial assistance to Bosnia and Herzegovina under the instrument for Pre-accession assistance (IPA III) entered into force 18 July 2022. [5]

3.2 Territorial cooperation (CBC)

Article 178 of the Treaty on the Functioning of the EU and Regulation (EU) No 1299/2013 defines the European Territorial Cooperation as the instrument of cohesion policy that aims to solve problems across borders and to jointly develop the potential of diverse territories. The objective of this financial instrument is to enhance the economic, social and territorial development of EU. This cooperation consists of cross-border, transnational and interregional cooperation. Legal basis for territorial cooperation is provided for in Article 178 of the Treaty on the Functioning of the EU and Regulation (EU) No 1299/2013. [13]

Bosnia and Herzegovina participates in three transnational cooperation programmes, as well as in three cross-border cooperation programmes: Interreg Euro-MED, Interreg IPA Adrion, Interreg Program Danube Region, Interreg IPA Croatia-Bosnia and Herzegovina-Montenegro, Cross-Border Cooperation Serbia-Bosnia and Herzegovina, Cross-Border Cooperation Bosnia and Herzegovina-Montenegro. [5]

3.3 Western Balkans Investment Framework (WBIF)

Western Balkans Investment Framework (WBIF) is a joint initiative of the European Commission and the partner international financial institutions (EIB - the European Investment Bank, EBRD - the European Bank for Reconstruction and Development, CEB - the Council of Europe Development Bank, the KfW Development Bank, the AFD - Agence Française de Développement and the World Bank Group - WB), aimed at unifying and coordinating various funding sources (primarily loans) with grant funds for the priority projects in the region. [5]

The WBIF consists of the Joint Grant Facility and the Joint Lending Facility. The funds of the Joint Grant Facility are intended for the projects supported by the loans of the partner international financial institutions (which informally cooperate in the Joint

Lending Facility), as well as other financial intermediaries, in the priority areas related with infrastructure construction, and other areas supporting socio-economic development. [14]

Key stakeholders of Western Balkans Investment Framework are: European Commission, six financial institutions, twenty bilateral donors and six beneficiaries. [14]

Western Balkans Investment grants are fully funded by donor contributions: [5]

- European Commission – the largest donor is the European Commission through the IPA funds,
- Bilateral donors – Austria, Czech Republic, Denmark, Finland, France, Greece, the Netherlands, Ireland, Italy, Canada, Luxembourg, Hungary, Norway, Germany, Poland, Slovakia, Slovenia, Spain, Sweden and Great Britain,
- International Financial Institutions (IFI): the European Investment Bank (EIB), the European Bank for Reconstruction and Development (EBRD), the Council of Europe Development Bank (CEB), the German Development Bank (KfW), the World Bank (WB), the Agence Française de Développement (AFD).

The IFIs pay a part of the grant funds in the Joint Fund and give loans to the beneficiary countries for individual projects. [5]

Beneficiary countries are potential candidates/EU membership candidates from Western Balkans: Albania, Bosnia and Herzegovina, Kosovo, Macedonia, Montenegro and Serbia. [14]

Area supported by WBIF are: transport, energy, environment, digital connectivity, social sector, private sector, other sectors that support socio- economic development, if approved by the Steering Committee of the Western Balkans Investment Framework. [14]

3.4 The EU programmes

Under the current cycle of EU programmes for the period 2021-2027, Bosnia and Herzegovina participates in the following programmes: Horizon Europe, Creative Europe, Single Market Programme-component Competitiveness and sustainability of SMEs, EU Civil Protection Mechanism, Fiscalis, Customs, Citizens, Equality, Rights and Values (CERV), EU4Health, Digital Europe, Justice and Erasmus+ (participation in activities within the international dimension of the programme). [1] [15] Within the Single Market Programme, Bosnia and Herzegovina also participates in the European exchange programme for new entrepreneurs: ERASMUS for Young Entrepreneurs. Bosnia and Herzegovina has also launched activities related to participation in additional programmes within the 2021-2027 cycle: Employment and Social Innovation (EaSI). [15]

3.5 The Macro-Regional Strategies

The macro-regional strategies do not have their own resources, but the funds are provided from the sources such as the European Structural and Investments Funds. The

expected outcomes of each macro-regional strategy are to define problems, to determine common goals, to participate in activities through projects and programmes and thus to provide long-term and efficient solutions that would benefit the country and a region. [16] Bosnia and Herzegovina is included in two macro-regional strategies: EU Strategy for the Danube Region (EUSDR) and EU Strategy for the Adriatic and Ionian Region (EUSAIR). Both strategies cover several pillars regarding the strengthening the region, protecting the environment and sustainability. [5]

3.6 Technical Assistance and Information Exchange

Technical Assistance and Information Exchange (TAIEX) is the short-term technical assistance and information exchange instrument of the European Commission at disposal to public administrations of both the pre-accession countries and the new Member States in the field of approximation and enforcement of EU legislation. [17] The role of TAIEX is to mediate between experts and users. The experts participating in the TAIEX instrument are exclusively from the EU Member States. The experts are usually representatives of the administration of an EU Member State and/or EU institution. The experts from individual universities may also be engaged. The Directorate for European Integration of the Council of Ministers of Bosnia and Herzegovina is the main coordinator of all TAIEX activities for Bosnia and Herzegovina. In Bosnia and Herzegovina, the beneficiaries of TAIEX assistance are the following: civil servants working in public administrations, the judiciary and law enforcements agencies, members of parliament and civil servants working in parliaments and legislative bodies, professional and commercial associations representing social partners, as well as representatives of trade unions and employers' associations. TAIEX does not provide direct support to civil society organisations, private citizens or to individual companies. [5]

4. Allocation of pre-accession funds

The EU is the single largest provider of funds and financial assistance in B&H. Since 1995, the EU has invested more than EUR 3,5 billion firstly towards post-war reconstruction and subsequently to assist B&H in its accession process across all key sectors. In doing so, the EU has been using a variety of financial instruments mentioned above in section 3, out of which the most comprehensive one is the Instrument for Pre-Accession Assistance. [18] Considering that Instrument for Pre-Accession Assistance is the EU's main financial instrument for assisting beneficiary countries in their gradual alignment with EU standards and policies, with the aim of EU membership, below are presented the allocations of IPA funds by program years and countries/thematic priorities and for the IPA I period utilizations.

Availability and utilization of pre-accession funds for IPA countries in the 2007-2013 programing period are presented in Table 1.

Table 1. IPA I 2007-2013 allocated and paid by country in million EUR

IPA I 2007-2013	TOTAL ALLOCATED	TOTAL PAID
Albania	520,94	468,76
B&H	521,77	517,80
Croatia*	813,38	730,47
Iceland	23,21	6,15
Kosovo	678,93	633,87
Montenegro	206,08	191,17
FYR Macedonia	478,46	427,13
Serbia	1344,57	1207,59
Turkey	4392,76	3960,51
Regional programs	1361,05	1323,71

*joined the EU on July 2013

Source: Creation of author according to web page of the European Commission: https://enlargement.ec.europa.eu/enlargement-policy/overview-instrument-pre-accession-assistance_en

In the period 2007-2013, the budget for IPA amounted to around EUR 10 billion. From the data in Table 1 it can be seen that in the first programming period the most funds were available to Turkey, Serbia and Croatia as the largest and the most significant countries in the integration process. Serbia had over EUR 1,34 billion available during the observed period, while about EUR 520 million was available to Bosnia and Herzegovina. Of the total funds from the IPA 2007-2013 state programs for Bosnia and Herzegovina, as of October 11 2019, 99% have been contracted. The percentage of total funds paid to companies that implemented projects from these state programs was also at the level of 99% according to data from October 2019. [19] Since B&H is in a decentralized system of managing EU financial assistance, the source of data on the contracting and disbursement of funds from IPA state programs is the EU Delegation to B&H. Financial aid was available to beneficiary countries, with a budget of 10.67 billion EUR for the period 2014-2020, in all policy areas, regardless of whether the country has candidate or potential candidate status. Indicatively allocated IPA II funds for Bosnia and Herzegovina, in the period 2014-2020, amount to EUR 539.6 million. The allocation of pre-accession funds by countries for the period 2014-2020 is presented in Table 2.

Table 2. Allocation of IPA II funds for the period 2007-2020 by country in million EUR

IPA II 2014-2020	TOTAL ALLOCATED*
Albania	758,0
B&H	539,6
Kosovo	573,1
Montenegro	269,2
FYR Macedonia/ North Macedonia	633,0
Serbia	1404,4
Turkey	3186,5
Multy-country	3319,7

* Including DG AGRI (IPARD), DG REGIO (CBC with MS) and EAC (Erasmus+)
Source: Creation of author according to web page of the European Commission:
https://enlargement.ec.europa.eu/enlargement-policy/overview-instrument-pre-accession-assistance_en

From Table 2 it is clear that for the programming period 2014-2020 most funds are allocated to Turkey and Serbia and at least to Montenegro and B&H. Still, there is no available data on IPA II payments. However, according to the last published data, of the total of EUR 285,86 million of IPA II funds for B&H for the national action programs for the period 2014-2018, as of 11 October 2019, 50% or EUR 143,15 million has been contracted. The percentage of funds disbursed from the national action programs 2014-2018 is at the level of 30% or EUR 86.79 million. [19] As stated above the main difference in relation to the instrument for pre-accession assistance for the period 2007-2013 was introduction of a sector approach in planning of the use of funds, enabling targeted assistance, ensuring efficiency, sustainability and focus on results. What made it possible for some funds to be withdrawn was the adoption of several important strategies at the state level, without which the allocation of funds would not be possible at all. The main weaknesses in the implementation of IPA II in B&H are the lack of coherent national strategies in key sectors with clear budget allocations and a medium-term expenditure framework. The highly decentralized structure with multiple levels of governance and the lack of functional coordination and policy-making mechanisms between different levels pose a challenge to ensuring strong leadership and effective sector and donor coordination at the national level. In the revised strategy IPA II for B&H, the European Commission stated that better coordination is needed between individual levels of government, in order to make the best possible use of the funds made available to B&H. [7]

With a budget of EUR 14.2 billion in the seven-year period 2021-2027 through IPA III instrument, the EU continues to financially support legal, economic and social reforms in candidate and potential candidate countries, enabling them to meet the criteria for membership in the EU. Unlike the previous two, the third generation of Instrument for Pre-Accession Assistance, abandons the principle of indicative financial allocations by country and replaces it with the principle of indicative financial allocations by windows. Therefore, the indicative allocation for the period 2021-2027 is according to thematic priorities common to all IPA III beneficiary countries presented in Table 3.

How much of these indicative amounts will be directed to individual IPA III beneficiary countries depends on the progress they make in implementing reforms, especially fundamental ones in the areas of the rule of law, public administration reform and sustainable economic development and competitiveness.

Table 3. Indicative allocation for the period 2021-2027 to support the thematic priorities of IPA III programming framework in million EUR

IPA III Windows	%	2021	2022	2023	2024	2025	2026	2027	Total
Window 1: Rule of law, fundamental rights and democracy	15,13	281	287	292	298	304	310	317	2.089
Window 2: Good governance, EU acquis alignment, good neighbourly relations and strategic communication	16,59	308	314	321	327	333	340	347	2.291
Window 3: Green agenda and sustainable connectivity	42,25	788	804	820	837	853	870	888	5.860
Window 4: Competitiveness and inclusive growth	22,31	414	422	431	440	448	457	467	3.080
Window 5: Territorial and cross-border cooperation	3,51	65	66	68	69	71	72	73	485
Total Operational Budget	100	1.855	1.894	1.932	1.971	2.010	2.051	2.093	13.804
Administrative Appropriations	n/a	49	49	50	51	52	53	54	357
Total	100	1.904	1.943	1.982	2.022	2.062	2.104	2.147	14.162

Source: European Commission: https://enlargement.ec.europa.eu/enlargement-policy/overview-instrument-pre-accession-assistance_en

5. Conclusions

European Union funds are the key investments both within the European Union for member states, as well as for states with candidate status and for third countries. Basically, the EU funds are intended separately for member states and non-member states. Programs and funds for non-member countries fall under the budget chapter of the EU as a global partner, and are actually assistance and cooperation programs.

Pre-accession funds are mainly intended for non-member states, while various EU programs and instruments of cohesion, agricultural, social policy, etc. are intended for member states. The EU financial instruments have intentions to support legal, economic and social reforms in candidate and potential candidate countries, enabling them to meet the criteria for the EU membership.

Due to its status on the European path, Bosnia and Herzegovina have access to certain funds offered by the EU. The EU aid and funds are always provided in accordance with a comprehensive strategy that is aligned with the circumstances of the development of the country.

In managing funds and its activities, the European Union relies on various financial and legal instruments. The most comprehensive is the Instrument for Pre-Accession Assistance. The pre-accession funds constitute at the same time a type of essential investment in the future of the countries in the process of enlargement and the European Union itself. The ultimate goal of all EU funding is to create better

conditions and improve the overall standard of living for all citizens of B&H. This is mostly done through providing funds for reforms and development, for example, of state institutions, non-governmental organizations, small and medium-sized enterprises, local governments, etc.

By obtaining EU candidate status, Bosnia and Herzegovina is opening up to: funds for regional development intended for the financing of infrastructure projects in the field of environment and transport, funds for increasing competitiveness, funds for the development of human resources intended for the preparation of cohesion policy, as well as the European Social Fund. Candidate status also gives access to the fund for rural development, which is intended for the preparation of the common agricultural policy. All these funds lead to the fulfilment of the conditions for entry into the full EU membership with all rights and obligations, as well as the creation of standards and quality of life for citizens in Bosnia and Herzegovina as EU citizens.

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Measuring the performance of non-profit organizations

Amel Džanić[1] and Alma Džanić[2]

[1]University of Bihać, Faculty of Technical Engineering, Bosnia and Herzegovina
[2]University of Bihać, Faculty of Law, Bosnia and Herzegovina

E-mail: alma.dzanic@unbi.ba

Abstract. The traditional, common measurement of organizational success is based on exact, financial indicators, primarily achieved business results and profit. With the development of democratic, civil societies, non-profit organizations, their activities and influence on improving the quality of all spheres of life are increasingly coming into focus. The primary goal of non-profit organizations is to provide services to society on a non-profit basis. Therefore, the success of non-profit organizations should be measured by how effectively they meet the needs of society. Financial indicators can play an enabling or constraining role, but they are inadequate for measuring the performance of non-profit organizations. For this reason, non-profit organizations use other, substitute indicators that show the success of their performance. This paper will present and analyse some of the methods for measuring the performance of non-profit organizations, and select and propose the most important non-financial indicators of success.

1. Introduction

Non-profit organizations are organizations whose primary goal is to achieve social benefit and serve the public. These organizations, as the name suggests, are not focused on making a profit, although they need it to achieve their mission. While profit organizations success is measured primarily through the realized profit, for non-profit organizations there is no single performance measure that would express their success. Therefore, it is necessary to establish different performance measures of non-profit organizations, which are related to the specificity of the activities of the non-profit organization.

The paper presents two models for performance measures of non-profit organizations. The Balanced Scorecard model proposes a multidimensional approach by supplementing financial indicators with non-financial ones. The second Input-Impact model places the mission and vision in the center of the model, through which the purpose and future of the organization are defined, followed by the determination of the strategy and organizational structure, as well as plans and ways of implementing

the mission and vision. This model also includes internal and external outputs, i.e. results achieved inside and outside the organization.

The last part of the paper presents the most suitable financial indicators of non-profit organizations for measuring performance, and as a selection of the authors, a proposal of non-financial indicators that non-profit organizations use to measure and evaluate performance and ultimately the success.

2. Definition and characteristics of non-profit organizations

Non-profit sector organizations exist to serve a social purpose, a constituency, or a cause. To do so successfully, they must earn or raise sufficient funds to cover expenses and safeguard the organization's future. They are not prohibited from creating excess revenue over expenses, but such surplus must be used to support the organization's mission, not to be distributed as private gain. In non-profit organizations there are no individual owners who can claim organizational assets for their own benefit. [1] In addition to the term of non-profit organizations, the following terms are also often used: voluntary, humanitarian, non-governmental, third sector organizations, civil society, social economy. Non-profit organization implies any organized group of people, voluntary organization, humanitarian agency, professional association, human rights organization, cooperative and similar form of organization, that are independent from the government, i.e. from state organizations and institutions. [2] The non-profit organizations can be understood by highlighting key, essential differences compared to the profit, commercial sector and the government sector. Most often, the following features stand out: their task is not defined in the field of economics, but in other segments of social needs, for example raising the educational level of the population, protection and health preservation, improvement of the cultural level of the population and its psychophysical abilities, development of humane relations in society, help to the vulnerable population, protection of the quality of the environment, universality that manifests itself in the provision of services that are not determined at the level of an individual user, but of all members of a community and availability of services to all members, complementarity of relations with the economic sector, etc. [3]

2.1 The importance of the non-profit organizations

Non-profit organizations make an essential contribution to the development and further survival and development of democratic societies, especially through improving public awareness and active participation of citizens in public life; likewise, they make an equally important contribution to the cultural life and social well-being of societies. In addition, the non-profit organizations have great importance in the social policy of developed countries, especially because they cannot meet all the needs of its citizens and therefore transfers many of its programs to the non-profit sector. Thus, the non-profit sector becomes an alternative and a new partner (but not a competitor) to the governmental sector, where people rely on their own strength in crisis situations. [1] [2].

The importance and role of non-profit organizations is reflected in the following: [4]

- support the decision-making process (authorities make decisions in accordance with needs);
- reduce the conflicts and increase the level of consensus;
- increase understanding, cooperation and respect for the efforts made by the government for the community;
- provide the support for the community development programs;
- increase transparency of government towards the needs of citizens;
- helps citizens to be better informed about the work of the government, but also of other sectors.

Considering the above-mentioned importance of non-profit organizations and the fact that, although they are a non-governmental sector, a large part of their financing comes from the sources of governmental institutions, so the question is how to define their success i.e. performance as a criterion for the allocation of funds.

3. Measuring the performance of non-profit organizations

Non-profit organizations have a primarily social focus and are increasingly market-oriented, while profit organizations strive to strengthen their social dimension of business by developing social responsibility. One of the key differences between nonprofit and profit organizations is the issue of measuring their performance. Until the 1990s, the success of organizational performance was viewed only through financial indicators. [5] The area of determining the success of non-profit organizations is characterized by exceptional complexity, and it must not be lost from the sight their originality, which stems from a specific social mission. Therefore, increasing attention and importance are being given to non-financial measures of organizational performance.

Performance measurement is the process of defining, monitoring and using objective indicators of the organization's performance, which is of vital importance for non-profit organizations. It aims to produce objective and relevant information about the performance of a program or organization that can be used to better manage and inform in decision-making process, achieve results and improve overall performance, as well as increase responsibility. [6]

From the above, it is clear what output measurement, or performance measurement, is for, but it is still necessary to emphasize that measurement cannot be performed unless it is preceded by adequate research into the variables that need to be measured depending on the purpose of the organization's existence.

3.1 Balanced Scorecard method

Companies today face various problems in developing a system for measuring the success of their organization. The Balanced Scorecard is a tool that helps organizations solve three main issues: measuring organizational performance, increasing intangible assets, and the challenges of implementing strategy. The Balanced Scorecard should provide a framework for transforming the vision and strategy of the organization into

measurable business objectives, as well as for measuring performance, especially in key business areas. [7]

Using Balanced Scorecard, four key dimensions or perspectives of organizational performance are grouped and measured, namely: customer perspective, internal process perspective, financial perspective and employee learning and growth perspective. Also, the name of Balanced Scorecard itself was created due to an attempt to harmonize, i.e. balancing financial and non-financial measures of organizational performance. [8]

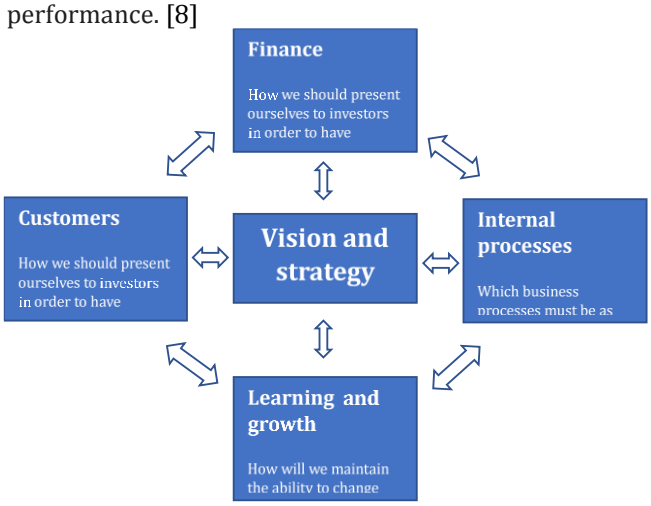

Figure 1. Key dimensions of the Balanced Scorecard model.

Customer perspective - under the analysis of this perspective, the organization must have answers to the questions: who are its clients, what added value it provides to clients, and what clients expect from cooperation with the organization. Depending on the activity, organizations have their target clients, but they implement a strategy of attracting a large number of clients. This can also be reflected as a lack of focus that can differentiate an organization from its competitors. When analyzing the customer/client's perspective, the most often are used: [8]

- customer satisfaction,
- customer loyalty,
- market share,
- customer retention rate,
- customer acquisition rate.

Internal process perspective - when analyzing internal processes, attention is paid to defining key processes in which an organization must be excellent in order to continue to add value for customers and other stakeholders. After defining the process, it is necessary to establish goals and develop measures to monitor progress. Within the internal process perspective, product development, time required for implementation, user adaptation, standardization, smooth process flow, after-sales service, transaction costs are observed. [8]

Employee learning and growth perspective – the goal of every organization is to increase organizational and individual capacities and abilities. The measures that are developed within this perspective are: job satisfaction, availability of information, development of workers' skills and abilities. [8]

Financial perspective is a key feature of Balanced Scorecard. The goals and measures defined within this perspective show whether the organization's strategy leads to improved financial results. The measures used in the financial perspective analysis are traditional financial measures, such as: profitability, asset utilization, added value, share price growth, etc. [8]

Non-profit organizations can use the Balanced Scorecard model for:

- clearer definition of mission and vision;
- identification of strategic goals (increasing member satisfaction, improving the business environment, strengthening the capacity and resources, increasing financial sustainability);
- financial perspective (i.e. sustainable financing, efficient use of funds and increase in income from membership fees);
- user perspective (members, community, interested parties through measurement of user satisfaction, number of financiers);
- internal business perspective (service efficiency, program quality and operational efficiency);
- the perspective of learning and growth (new training and development of employees, technological improvements and innovative practices);
- defining key performance indicators;
- creating a Balanced Scorecard folder;
- implementation and communication;
- continuous monitoring and adjustment.

3.2 Input – Impact model

The Input-Impact model puts organization's mission and vision at the center, followed by strategy and organizational structure, and includes internal and external outputs. [9]

The following diagram provides a generalized Input-Impact model that can be applied to any non-profit organization. [9]

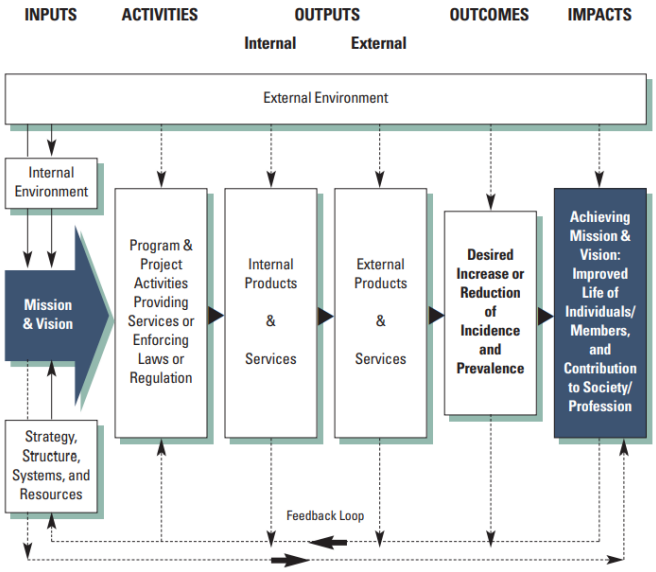

Figure 2. Input-impact model for non-profit organizations.

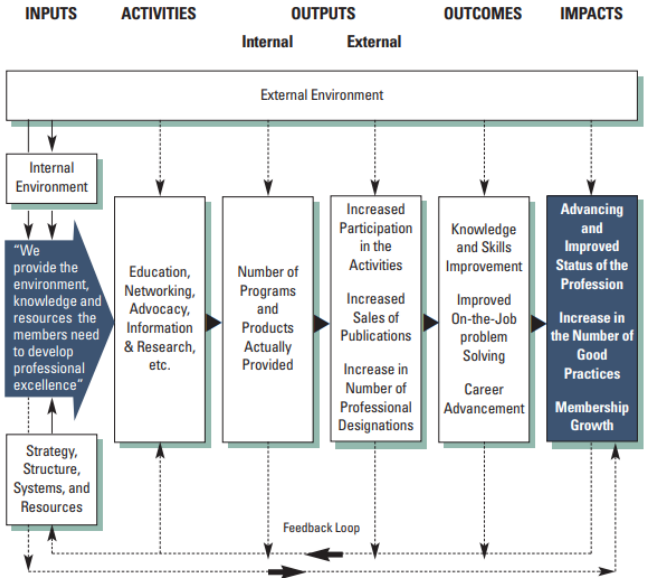

Figure 3. Input-impact model for professional associations.

The next presented diagram shows practical use of Input-Impact model for professional associations/organizations such as labour unions, trade associations, chamber of commerce etc. Activities of professional associations and other business

and professional non-profit organizations typically include educational services, networking, advocacy, advocacy, and research. Internal results refer to: [9]

- number of programs, services and products provided (newsletters and published magazines);
- constant access to databases and necessary information;
- seminars, workshops and other organized events.

External influences include increased participation of members in activities, increased sales of publications, increased number of professional advancements, etc. Expected outcomes as a consequence of these results would usually include the following individual benefits: improvements in knowledge and skills, better problem solving at the workplace, career advancement, etc. In some cases, for example members receive professional designations, even higher salaries may be considered an outcome. Finally, impacts related to the profession may include advancement and improvement of status, growth in membership, and overall growth in the quality of professional practice. [9]

The following illustration provides a visual representation of the cause-and-effect relationships between the previously mentioned elements. [9]

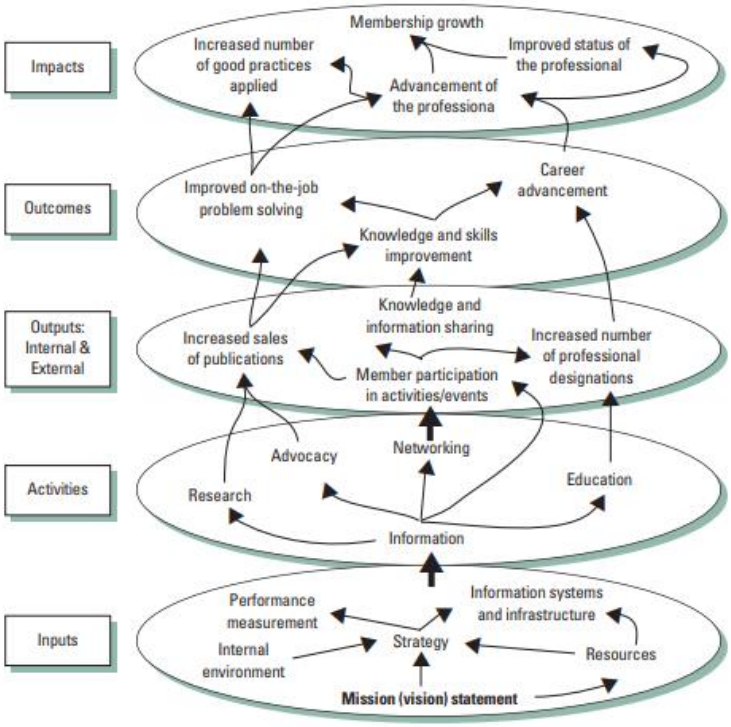

Figure 4. Causality map-drivers of influence for professional associations.

The impact driver causality map shows the number of potential results that arise from organized and implemented activities and programs, results such as increased knowledge and information exchange that, in turn, lead to improved knowledge and skills of members. [9]

The above presented table gives an overview of examples of measures that support the elements of a cause-and-effect relationship and thus could be the variables for performance measurement for professional associations.

4. Financial and non-financial performance measures for non-profit organizations

Performance measures are objective, quantitative indicators of various aspects of the organization, and are defined through different types of measures for monitoring certain dimensions of performance, such as: [6]

- efficiency,
- work efficiency,
- productivity,
- service quality,
- customer satisfaction and
- cost-effectiveness.

The importance of performance measurement is particularly important in strategic planning. Although the terms strategic planning and strategic management are often equated, there is a difference between them. Strategic planning is the process of clarifying the mission and vision, defining the main objectives and developing long-term strategies for the future development of the organization in a purposeful manner and ensuring a high level of performance in the long term. In contrast, strategic management is a broader process that is responsible for developing strategic plans, implementing strategic initiatives and continuously evaluating their effectiveness. [6]

Every non-profit organization can measure performance using financial and non-financial indicators. The reason for this is that financiers, donors, managers, and others primarily use financial indicators to evaluate the performance of non-profit organizations. However, although financial indicators are very important, they alone cannot provide a comprehensive overview of organizational performance. [9]

The following tables will provide concrete representations of some of the most appropriate financial and non-financial indicators that non-profit organizations use to measure and evaluate performance and ultimately success. [9] [10]

Table 1. Model Input – Impact: example of measures for professional ssociations/organizations

CATEGORY	PERFORMANCE MEASURMENT
Inputs	- % of alignment of strategic priorities with the mission (vision) - % of growth of number of full-tine employees

	- employee commitment to achieving mission (vision) - operational sustainability (operating income as % of costs) - funds available to investment in IT infrastructure - % of documented and measured activities
Activities	- % of realization of planned activities - % of increase of funds invested in various activities - % of employees actively involved in activities
Outputs	- % of increase of member participation in various activities - % of participant satisfied with the overall quality of activities provided - website functionality (number of visits) - % of increase of staff consultation and advocacy - % of members who use networks to advance their careers - % of increase in the number of professional designations
Outcomes	- % of members who had advance in their careers based on a professionally acquired designation - % of member who claim to have improved their experience at work in terms of problem solving - % of members who claim to have acquired significant new knowledge - % of members who claim to have acquired useful new skills for their profession
Impacts	- % of members who have implemented new practice in their organizations - % of members who claim to have improved their organizations by implementing new practice - no. of successful interventions in determining new relevant legislation - % of increase of members

Source: Epstein J M Buhovac R A p 46

Table 2. Examples of financial performance measures for non-profit organizations

CATEGORY	PERFORMANCE MEASURMENT
Administrative efficiency	- administrative costs divided by total costs; - % of income spent on administrative costs
Program effectiveness	- program support or charitable commitment (% of total costs directly for charitable purposes);

	- program costs divided by total costs; - growth of program costs - current consumption factor (total costs divided by total income); - program output index (number of units of actual physical output divided by total program costs); - productivity rate (outputs divided by inputs)
Fundraising efficiency	- % of donations remaining after deducting the costs of obtaining them; - % of income spent on fundraising costs; - fundraising costs divided by total costs; - donor dependency (operating surplus minus donations, divided by donations)
Other financial measures	- revenue growth; - working capital ratio (working capital divided by total costs)

Source: Epstein J M Buhovac R A p 7

Table 3. Examples of non-financial performance measures for non-profit organizations

CATEGORY	PERFORMANCE MEASURMENT
Mission, vision, goals	- compatibility of misison, vision and goals - the organization's mission is woven into every activity, the purpose is clearly visible - goals are set as „SMART“
Image	- percepcion of environment - benchmarking; - internal evaluation - crisis management
Value	- social impact - quality of services and programs - transparency and accountability
Client satisfaction	- on-site feedback - number of clients - complaint analysis - availability of information

Sources: Creation of authors

5. Conclusion

Nowadays, the requirements for measuring the performance of the non-profit organizations have increased due to their increasing social, political and economic influence.

The specificities of non-profit organizations have led to the fact that some authors, who deal with this field, exclude the possibility of using financial indicators, while others propose a multidimensional approach, by supplementing financial criteria with non-financial ones (e.g. Balanced Scorecard) in order to balance the financial perspective, which, however, has a secondary importance for non-profit organizations.

The benchmarks and measurement of the performance of non-profit organizations derive from their mission and cannot be expressed only by financial indicators or traditional financial performance. For them, non-financial indicators are relevant and it is necessary to establish the measurement of predetermined performances that are related to the specificity of the non-profit organization's activities. Thus, for example, the Input-Impact model can be used to measure the performance of all types of non-profit organizations or, for example, special types of non-profit organizations such as professional associations. Looking at a non-profit organization from a financial perspective will always remain important because incurred losses can lead to the collapse of any organization. Therefore, a set of qualitative and quantitative, non-financial and financial performance measures of non-profit organizations is proposed. These performance measures would include measures of input or resources, measures of output or results, measures of quality (service), measures of effectiveness (planned/achieved), measures of efficiency (output/input).

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The Impact of Mobile Banking Application Quality on Customer Loyalty: The Mediating Role of Satisfaction and the Moderating Role of User Characteristics

Kenan Mahmutović

University of Bihać, Faculty of Economics, Bosnia and Herzegovina

E-mail: kenan.mahmutovic@gmail.com

Abstract. This study examines the impact of perceived mobile banking application quality on customer satisfaction with mobile banking services and, in turn, on overall satisfaction and loyalty toward the bank. Drawing on service quality, satisfaction, and digital loyalty theories, a structural equation model was developed and tested using data from 267 mobile banking users in Bosnia and Herzegovina. Results confirm that application quality significantly predicts satisfaction with mobile banking ($\beta = 0.346$, $p < 0.001$), which in turn fully mediates its effect on bank-level loyalty (indirect effect $\beta = 0.227$, $p < 0.001$). The validated Mobile Banking Application Quality (MBAQ) scale, refined to 10 items, demonstrated excellent reliability and validity. Multigroup SEM revealed that age, education level, and payment frequency significantly moderated model paths, highlighting the importance of user segmentation. The study underscores the strategic role of mobile app quality in shaping satisfaction and loyalty in digital banking, offering theoretical insights and practical implications for financial institutions.

1. Introduction

The rapid digital transformation of the financial services industry has fundamentally reshaped how customers interact with banks. Among the most transformative innovations is mobile banking (m-banking), which enables users to access a wide range of banking services, from checking balances to executing complex transactions, through mobile applications on smartphones and tablets (Ayala Gavilanes et al., 2023; Iswani, 2023). As part of the broader electronic banking (e-banking) ecosystem, mobile banking has gained significant traction due to its accessibility, efficiency, and alignment with evolving consumer expectations (Shaikh & Karjaluoto, 2015; Adhikari & Gyawali, 2023).

As mobile banking becomes the dominant channel for everyday banking activities, the quality of mobile applications has emerged as a critical determinant of customer satisfaction, trust, and continued usage. The app is no longer just a functional interface, it is the primary medium through which banks deliver value and maintain customer

relationships (Oh & Kim, 2022; Mbama et al., 2018). High-quality apps that offer intuitive design, security, and responsiveness contribute to positive customer experiences, key drivers of satisfaction and long-term loyalty (Chatterjee et al., 2022; Parasuraman et al., 2005).

Despite widespread adoption, a gap exists in understanding how specific mobile banking application quality dimensions influence customer satisfaction. While models such as SERVQUAL (Parasuraman et al., 1988) and E-S-QUAL (Parasuraman et al., 2005) have been extensively applied in digital contexts, their adaptation to mobile app environments is still evolving. In particular, limited empirical work has explored how app-specific dimensions, such as ease of use, reliability, security, and efficiency, affect users' cognitive and emotional evaluations of service quality (Jun & Palacios, 2016; Sharma & Malviya, 2013).

The core problem addressed in this study is the limited understanding of how users' overall perception of mobile banking application quality shapes their satisfaction with the service and how this satisfaction extends to influence their loyalty toward the bank. This issue is particularly pertinent in contexts where mobile apps serve as the primary interface between customers and financial institutions. Accordingly, the study aims to examine the chain of relationships linking perceived application quality, user satisfaction with mobile banking, and broader customer loyalty. The research is guided by the following questions:

- RQ1**:** Does mobile banking application quality affect customer satisfaction with mobile banking services?
- RQ2**:** To what extent does satisfaction with mobile banking services influence satisfaction and loyalty toward the bank?
- RQ3**:** Does satisfaction with mobile banking mediate the relationship between application quality and overall loyalty to the bank?

The paper's structure is organized as follows: Section 2 presents a comprehensive literature review on mobile banking, service quality, and customer satisfaction metrics. Section 3 introduces the conceptual model and develops the research hypotheses. Section 4 outlines the research methodology, including sample characteristics, data collection instruments, and analysis techniques. Section 5 reports the empirical results, while Section 6 discusses the findings, theoretical implications, and managerial recommendations. In the final section, the paper summarizes the conclusions, reflects on the study's limitations, and identifies potential areas for further investigation.

2. Literature Review

2.1 Mobile Banking and Customer Experience

Mobile banking (m-banking), a subset of electronic banking (e-banking), refers to using mobile devices, such as smartphones and tablets, to access banking services remotely. This enables users to perform both financial and non-financial transactions at any time and from any location (Ayala Gavilanes et al., 2023; Iswani, 2023). These services

typically include balance inquiries, fund transfers, bill payments, transaction history access, and card management via institution-specific mobile applications. More broadly, electronic banking encompasses banking services via electronic channels, including online portals, ATMs, and mobile interfaces. It has redefined the delivery of financial services by minimizing the need for face-to-face interactions, supporting transactional automation, and enhancing service accessibility (Adhikari & Gyawali, 2023; Mwakisoba & Meela, 2024).

The transformation of traditional banking models through e-banking has been driven by customers' increasing expectations for speed, convenience, and uninterrupted access to services, as well as by banks' strategic objectives to reduce costs and optimize efficiency (Shaikh & Karjaluoto, 2015). Mobile banking has emerged as the dominant channel within this transformation due to smartphone penetration, reliable mobile internet, and intuitive app ecosystems (Ayala Gavilanes et al., 2023).

Mobile banking is not merely a technological innovation but a fundamental shift in how financial institutions interact with customers. It has expanded from transactional functionality to offer real-time alerts, investment management, and financial planning tools, fundamentally reshaping the customer experience.

Customer experience (CX) is critical in evaluating mobile banking, where perceived ease of use, responsiveness, trust, and personalization replace traditional face-to-face service drivers (Adhikari & Gyawali, 2023; Oh & Kim, 2022). For instance, Oh and Kim (2022) identified ease of use, convenience, security, and customer support as key dimensions influencing satisfaction with mobile apps based on an analysis of over 90,000 reviews. These insights align with the Technology Acceptance Model (TAM), which emphasizes perceived usefulness and ease of use as central to digital adoption (Gu et al., 2009; Luarn & Lin, 2005).

As mobile banking is a cognitively and emotionally engaging experience, customers evaluate it through both rational (transactional efficiency, reliability) and affective (trust, confidence) lenses (Gentile et al., 2007; Iswani, 2023). Security, in particular, plays a crucial role in shaping perceptions of trustworthiness and reliability. Studies confirm that technical, functional, informational, or service-related failures negatively affect satisfaction and usage intentions (Sugiono et al., 2025).

Furthermore, generational characteristics also influence mobile banking perceptions. For example, Gen Z users prioritize speed and digital intuitiveness, while older cohorts focus more on trust and security (Iswani, 2023). As such, segmentation and personalized design strategies are essential.

Ultimately, customer experience in mobile banking is directly linked to satisfaction, loyalty, and continued usage. Improvements in perceived service quality foster stronger customer relationships (Adhikari & Gyawali, 2023).

2.2 Service Quality in Digital Contexts

Service quality (SQ) remains a foundational construct in service marketing theory, widely acknowledged as a determinant of customer satisfaction, behavioral intention, and long-term loyalty (Parasuraman et al., 1988; Zeithaml et al., 2002). Traditionally, the SERVQUAL model provided a multidimensional framework for evaluating perceived service performance, focusing on five core dimensions: reliability, responsiveness, assurance, empathy, and tangibles (Parasuraman et al., 1988). However, transitioning from physical to digital service environments has necessitated reconfiguring these dimensions to reflect the virtual nature of customer-firm interactions.

Parasuraman, Zeithaml, and Malhotra (2005) introduced the E-S-QUAL model, a tailored approach for assessing electronic service quality to address these limitations. This model emphasizes four primary dimensions: efficiency, system availability, fulfillment, and privacy, while its complementary E-RecS-QUAL subscale evaluates service recovery. E-S-QUAL has become one of the most cited and applied models in digital banking, e-commerce, and online customer service, offering high construct validity in web-mediated environments (Ladhari, 2010; Bauer et al., 2005). Empirical studies have confirmed the applicability and robustness of E-S-QUAL in diverse digital settings. Bauer, Hammerschmidt, and Falk (2005) validated its use in online banking portals, showing that system availability and privacy are particularly salient predictors of customer trust and usage intention. Similarly, Jayawardhena (2004) developed an Internet banking-specific scale that adapted SERVQUAL components to better align with the self-service nature of digital channels.

Further extensions of service quality models include Santos (2003), who proposed a virtual service quality model encompassing both traditional functional dimensions (e.g., responsiveness, reliability) and online-specific factors such as interactivity, design, and web navigability. This approach aligns with findings by Yang and Fang (2004), who emphasized that dimensions like information content, website aesthetics, and transactional reliability significantly influence customer satisfaction and trust in online financial services.

Recent research also integrates service quality evaluation with behavioral theories and data analytics. For instance, Kassim and Abdullah (2010) used structural equation modeling to demonstrate that perceived e-service quality significantly affects customer satisfaction, trust, and loyalty, especially in cross-cultural e-commerce settings. Similarly, Ahmed et al. (2020) applied multivariate analysis techniques to validate the ES-QUAL model in online banking and found strong system reliability and fulfillment effects on satisfaction.

Moreover, digital service quality research is increasingly aligned with service-dominant logic, where value is co-created through customer interaction with digital systems, rather than merely delivered by the firm (Roy et al., 2015). In this view, service quality extends beyond system features, including personalization, emotional experience, and cognitive load reduction (Chatterjee et al., 2022; Grigoroudis & Siskos,

2010). In the specific context of mobile banking, these models must further account for device heterogeneity**,** touchscreen usability, and network latency, all of which influence perceived quality. As such, mobile-specific frameworks, like those proposed by Jun and Palacios (2016) and Sharma and Malviya (2013)**,** incorporate dimensions such as **ease** of navigation**,** mobile responsiveness, and real-time feedback, which traditional e-service models do not fully capture.

The evolution from SERVQUAL to E-S-QUAL and beyond reflects the broader shift toward digital and mobile service delivery. As customers increasingly evaluate service quality through interface performance**,** security protocols, and digital support, research must continue to adapt and refine measurement tools that capture digital service environments' functional, emotional, and contextual realities.

2.3 Dimensions of Mobile Banking Application Quality

In mobile banking, service quality models must reflect the specific attributes of app-based service delivery. Jun and Palacios (2016) proposed a dual structure distinguishing customer service and application quality. They identified eight core app dimensions: content, accuracy, ease of use, speed, aesthetics, security, feature diversity, and convenience. Ease of use, mobile convenience, and accuracy were most frequently cited as satisfaction drivers.

Subsequent studies expanded this model. Shankar et al. (2020) added interactivity, customer support, and content as key qualitative dimensions. Zhou et al. (2021) highlighted the significance of interface design, reliability, and security, while Nisha (2016) integrated TAM-based constructs such as perceived control and usefulness. Ahmed et al. (2020) demonstrated that system availability, privacy, and efficiency positively affect satisfaction via perceived value and trust. Arcand et al. (2017) differentiated between utilitarian and hedonic dimensions, showing that enjoyment and social connectivity influence relationship quality. Usability remains a foundational element. Hussain et al. (2014) proposed five usability factors that influence app adoption and retention: efficiency, effectiveness, learnability, satisfaction, and error prevention.

Despite a growing consensus around specific dimensions (ease of use, security, accuracy), inconsistencies remain in how features like aesthetics and convenience are operationalized. Few studies explicitly link app quality to behavioral outcomes such as loyalty, churn, or engagement, gaps that future research should address.

2.4 Customer Satisfaction and Loyalty Metrics

Customer satisfaction, conceptualized as a cognitive-affective evaluation (Oliver, 1997; Yi, 1991), is a dynamic judgment formed through both rational assessments and emotional experiences. In banking, satisfaction is a strategic predictor of loyalty, retention, and long-term profitability (Roy et al., 2015; Grigoroudis & Siskos, 2010).

While traditionally evaluated using models like expectancy-disconfirmation (Oliver, 1980) and SERVQUAL (Parasuraman et al., 1988), satisfaction metrics have evolved in digital contexts. The Net Promoter Score (NPS), developed by Reichheld (2003), has become a widely accepted tool for gauging customer loyalty by capturing willingness to recommend. Although NPS is positioned as a loyalty metric, recent studies suggest it reflects satisfaction, especially in mobile contexts where positive app experiences are closely tied to higher NPS ratings (Bhale, 2024; Roy Morgan Research, 2021). NPS thus bridges satisfaction and advocacy, integrating cognitive and affective elements of customer evaluation.

Research confirms that satisfaction is a prerequisite for loyalty but not its sole determinant (Hallowell, 1996; Anderson & Mittal, 2000). Factors such as switching costs, digital convenience, and perceived differentiation also shape customer retention. In banking, where relationships are long-term and trust-based, satisfaction with digital services strongly predicts both attitudinal and behavioral loyalty.

2.5 Measuring Satisfaction in Banking and Mobile Financial Services

In digital banking, satisfaction metrics are integral to experience management. Mbama et al. (2018) confirmed that usability, personalization, and perceived value strongly influence satisfaction and loyalty. Chatterjee et al. (2022) and Roy et al. (2015) emphasize the importance of combining structured metrics like NPS with unstructured feedback (e.g., app reviews) for a comprehensive evaluation.

In mobile contexts, satisfaction is multidimensional. Functional elements like reliability and speed are assessed alongside affective dimensions like trust and emotional comfort (Chatterjee et al., 2022; Mbama et al., 2018). NPS, in particular, integrates both domains: the recommendation question invokes memory (cognition) and emotion (affect) (Reichheld, 2003).

Recent empirical findings support NPS as a valid satisfaction proxy. The J.D. Power (2025) study found that mobile UX improvements boosted NPS and satisfaction. Accenture (2022) observed an average NPS of +24 for mobile apps, linking higher scores with trust and usability. Bain & Company (2023) reported that banks offering superior digital experiences achieved faster revenue growth and higher NPS values. Bhale (2024) further showed that digital engagement significantly affects NPS, moderated by age and usage patterns.

These findings affirm that NPS is a robust hybrid metric for satisfaction and loyalty in mobile banking, especially when triangulated with Customer Satisfaction Score (CSAT) and Customer Effort Score (CES) for more profound insight.

3. Conceptual Model and Hypotheses Development

3.1 Conceptual Framework

Building on the preceding literature, this study proposes a conceptual framework to examine how users' perceptions of mobile banking application quality affect their satisfaction with mobile banking and, subsequently, their satisfaction and loyalty toward the bank as a service provider. The model draws on established theories in service quality (Parasuraman et al., 1988), satisfaction (Oliver, 1997), and loyalty (Reichheld, 2003), particularly within digital financial services. In this framework, the "perceived quality of mobile banking applications" is conceptualized through five dimensions adapted from Sharma and Malviya (2013): (1) Reliability and Responsiveness, (2) Assurance and Security, (3) Convenience, (4) Efficiency, and (5) Ease of Operation. While these dimensions provide the conceptual foundation of the construct, the present study focuses on analyzing the overall effect of perceived mobile banking application quality on users' "satisfaction with mobile banking", as measured by the mobile-specific Net Promoter Score (NPS). This mobile-specific satisfaction is then posited to predict users' broader "satisfaction and loyalty toward their bank", captured through a second NPS item reflecting overall bank recommendation.

The framework introduces a "mediated relationship", where mobile app quality affects bank-level satisfaction and loyalty through the intermediary of mobile banking satisfaction. This reflects the evolving structure of customer journeys in digital ecosystems, where individual touchpoints shape holistic brand perceptions.

3.2 Hypotheses Development

Mobile Application Quality and Satisfaction with Mobile Banking

Prior research consistently identifies service quality as a key antecedent of customer satisfaction in both traditional and digital banking contexts (Parasuraman et al., 2005; Sharma & Malviya, 2013). In mobile banking, users' evaluations of the application's functionality, reliability, and user interface are crucial in shaping satisfaction. Accordingly, the following hypothesis is proposed:

> H1: Perceived quality of the mobile banking application positively affects customer satisfaction with mobile banking services (measured via NPS).

Satisfaction with Mobile Banking and Loyalty Toward the Bank

The literature on relationship marketing and customer behavior demonstrates that satisfaction with specific service encounters or channels can extend to brand satisfaction and loyalty (Anderson & Mittal, 2000; Mbama et al., 2018). In banking, satisfaction with mobile services may translate into broader trust and commitment toward the institution. Thus, the following hypothesis is proposed:

> H2: Satisfaction with mobile banking (measured via mobile NPS) positively influences satisfaction and loyalty toward the bank (measured via bank NPS).

Mediating Role of Satisfaction with Mobile Banking

Building on the expectancy–disconfirmation theory (Oliver, 1980) and customer loyalty models, satisfaction is often conceptualized as a mediating mechanism through which service quality influences loyalty-related outcomes. In the context of mobile banking, it is expected that users' satisfaction with mobile services bridges the relationship between application quality and overall loyalty toward the bank. Therefore, the following hypothesis is proposed:

H3: Satisfaction with mobile banking mediates the relationship between perceived mobile application quality and satisfaction/loyalty toward the bank.

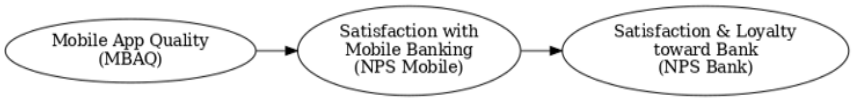

Figure 1. Proposed Research Model Linking Mobile App Quality, Satisfaction, and Loyalty

The proposed research model shown in Figure 1 provides a robust basis for assessing both direct and indirect effects of mobile application quality on higher-level customer outcomes in the banking industry.

4. Methodology

4.1 Research Design

This study adopts a quantitative, cross-sectional research design to empirically test the hypothesized relationships between perceived mobile banking application quality, customer satisfaction with mobile banking, and overall satisfaction and loyalty toward the bank. A survey-based data collection strategy was employed, allowing for standardized measurement of latent constructs and statistical generalization across a population.

4.2 Sample and Data Collection

The target population comprises active users of mobile banking applications in Bosnia and Herzegovina. Data were collected using a structured online questionnaire distributed through digital channels. The final sample includes 267 valid responses, exceeding the recommended minimum sample size for structural equation modeling (SEM) as Hair et al. (2019) suggested.

Respondents were screened to ensure they had recent experience using a mobile banking app and could identify their primary banking institution. Participation was voluntary, and confidentiality was assured.

4.3 Measurement Instruments

This study employed a structured questionnaire to assess users' perceptions of mobile banking application quality, satisfaction with the mobile app, and satisfaction and loyalty toward the bank. Perceived mobile banking application quality was measured using a multi-item scale based on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree). Specifically, the items were adapted from a scale originally developed by Sharma and Malviya (2013) in their study *Exploring the Dimensions of Mobile Banking Service Quality*. From the original pool of 28 items, 15 were selected based on their theoretical relevance to the mobile application interface, as opposed to general mobile banking services. These selected items are listed in Appendix A. All items were translated, reviewed by experts, and culturally adapted to the local context.

Satisfaction with the mobile app and overall satisfaction and loyalty toward the bank were each assessed using single-item Net Promoter Score (NPS) indicators, rated on an 11-point scale ranging from 0 (not at all likely) to 10 (extremely likely).

4.4 Data Analysis Procedures

Data analysis was conducted using the R statistical environment and proceeded through the following stages:

Descriptive Statistics
Descriptive analyses were used to summarize respondents' key demographic characteristics and behavioral patterns.

Exploratory Factor Analysis (EFA)
EFA was applied to assess the dimensionality of the mobile banking application quality (MBAQ) scale and identify the underlying factor structure based on item loadings.

Confirmatory Factor Analysis (CFA)
CFA was performed to validate the measurement model and evaluate construct validity, including convergent and discriminant validity criteria.

Reliability Analysis
Internal consistency of the MBAQ scale was assessed using Cronbach's alpha and composite reliability (CR) indices.

Structural Equation Modeling (SEM)
SEM was employed to test the hypothesized relationships among constructs and examine mediation effects as outlined in the conceptual framework.

Mediation Analysis
The indirect effect of app quality on bank-level satisfaction and loyalty, mediated by satisfaction with mobile banking—was tested using the bootstrap method with bias-corrected confidence intervals.

Multigroup SEM (Moderation Analysis)
Multigroup SEM was conducted across predefined demographic (age, education) and behavioral (usage frequency) subgroups to investigate potential moderation effects. Differences in structural path coefficients were evaluated using chi-square difference tests (likelihood ratio tests).

4.5 Ethical Considerations
The research adhered to ethical standards for human subject research. Informed consent was obtained from all participants prior to data collection. Respondents were informed of their right to withdraw at any time, and all responses were anonymized to protect personal data.

5. Empirical Results

5.1 Sample Profile and Descriptive Statistics
The final sample consisted of 267 respondents who reported using mobile banking services. The demographic structure of the sample reveals a predominance of female users (65.9%) compared to male users (34.1%). The majority of respondents were aged between 41 and 50 years (44.9%), followed by the 31–40 age group (26.6%) (see Table 1). Younger users (aged 18–30) represented a smaller segment (9.4%), while 19.1% were aged 51 or older.

Table 1. Sample Distribution of Mobile Banking Users by Age and Gender

Age	Female %	Male %	Total %	Frequency
18 - 30	7.12	2.25	9.37	25
31 - 40	16.48	10.11	26.59	71
41 - 50	29.59	15.36	44.95	120
51 and more	12.73	6.37	19.1	51
Total %	65.92	34.08	100	267
Frequency	176	91		

Source: Author

Regarding educational attainment and employment status, 63.7% of participants held a bachelor's degree, and 13.9% held a master's or doctoral degree. A substantial share (22.5%) had completed secondary school or less. Most respondents were employed (87.3%), with smaller proportions being self-employed (8.2%), unemployed (2.2%), or retired (2.2%) (see Table 2).

Table 2. Sample Distribution of Mobile Banking Users by Education and Employment

Education	Employed %	Retired %	Self - employed %	Unemployed %	Total %	Frequency
Bachelor's degree	57.68	1.5	3	1.5	63.68	170
Master's or Doctoral degree	13.48	0	0	0.37	13.85	37
Secondary school or lower education	16.1	0.75	5.24	0.37	22.46	60
Total %	87.27	2.25	8.24	2.25	100	267
Frequency	233	6	22	6		

Source: Author

Bank affiliation data show that UniCredit Bank had the largest share of mobile banking users (38.6%), followed by Sparkasse Bank (15.0%) and Raiffeisen Bank (12.4%). Most respondents had been clients of their bank for more than three years (71.9%), suggesting a stable and experienced user base. Only 0.75% had been clients for less than six months (see Table 3).

Table 3. Sample Distribution of Mobile Banking Users by Bank Name and Client Duration

Bank	Up to 6 months (%)	From 6 to 12 months (%)	From 1 to 3 years (%)	Longer than 3 years (%)	Frequency	Total %
ASA banka	0.37	1.87	4.12	4.87	30	11.23
Adicco banka	0.37	0.75	0.37	0.37	5	1.86
BBI banka	0	0	1.5	4.12	15	5.62
NLB banka	0	0.75	2.62	3.75	19	7.12
Raiffeisen banka	0	0.75	2.25	9.36	33	12.36

Sparkasse banka	0	1.5	5.62	7.87	40	14.99
UniCredit banka	0	0.75	1.5	36.33	103	38.58
Ziraat banka	0	0.75	2.25	5.24	22	8.24
Total %	0.75	7.12	20.22	71.91	267	100
Frequency	2	19	54	192		

Source: Author

Behavioral patterns related to banking activities revealed that mobile banking was the most frequently used service channel. Specifically, 50.2% of users checked their account balance via mobile banking weekly, and 35.2% did so daily. Card payments were also frequently used, with 58.8% reporting daily use. In contrast, traditional branch visits were much less frequent—only 13.1% of users reported never visiting a branch, and just 5.9% did so daily. Bill payments through mobile banking occurred monthly for 31.8% of respondents, and 23.9% used this function weekly (see **Table 4**).

Table 4. Sample Distribution of Mobile Banking Users by Banking Behavior

Banking Behavior	Never (%)	Several times a year (%)	Monthly (%)	Weekly (%)	Daily (%)
Branch visits	13.11	46.82	26.22	7.87	5.99
ATM cash withdrawals	2.25	9.36	32.58	40.45	15.36
M-banking: balance check	0.75	2.62	11.24	50.19	35.21
Card payments	3.37	2.62	7.87	27.34	58.8
M-banking: bill payments	10.86	16.85	31.84	23.97	16.48
Online payments	22.47	23.6	22.47	15.36	16.1

Source: Author

Finally, descriptive statistics for the primary constructs of interest—mobile banking app quality and Net Promoter Scores (NPS) for mobile banking and the bank overall—are summarized in **Table 5**. On average, perceived app quality scores were highest among users of Adicco Bank (M = 46.8, SD = 3.83), followed by Ziraat Bank and Sparkasse Bank. The overall average across all banks was 39.2 (SD = 9.42). The average NPS for mobile banking was 8.75 (SD = 1.66), while the bank-level NPS averaged 8.17 (SD = 1.84). Median values and interquartile ranges (IQR) suggest that both NPS scores

are relatively high and moderately concentrated around the upper part of the 0–10 scale.

Table 5. Descriptive Statistics for Mobile Bank App Quality ratings, Bank NPS and M-banking NPS

	M-Banking App Quality		Net Promoter Score (Bank)				Net Promoter Score (M-Banking)				
Bank	Mean	SD	Mean	SD	Median	IQR	Mean	SD	Median	IQR	Count
ASA banka	38.9	8.24	8	1.66	8	2	8.47	1.36	8.5	2	30
Adicco banka	46.8	3.83	9.2	0.84	9	1	9.2	0.84	9	1	5
BBI banka	40.7	4.99	7.8	1.52	8	1	8.47	1.36	8	1.5	15
NLB banka	39.2	8.11	8.16	2.27	9	1.5	8.42	1.46	9	1	19
Raiffeisen banka	38.4	10.3	8.03	1.74	9	2	8.48	1.62	9	1	33
Sparkasse banka	40.6	8.29	8.68	1.25	9	2	9.2	0.76	9	1	40
UniCredit banka	37.9	10.8	8.08	1.99	8	3	8.86	1.85	10	2	103
Ziraat banka	41.3	6.11	8.18	2.3	8.5	2.75	8.59	2.59	10	1.75	22
Total (all banks)	39.2	9.42	8.17	1.84	8	2	8.75	1.66	9	2	267

Source: Author

5.2. EFA and CFA for Mobile Banking App Quality Scale (MBAQ)

Exploratory Factor Analysis (EFA)

An Exploratory Factor Analysis (EFA) was conducted on a sample of 267 active mobile banking users to assess the empirical structure of the scale. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.96, and Bartlett's test of sphericity was significant ($\chi^2 = 4470.78$, df = 78, $p < .001$), indicating suitability for factor analysis (Hair et al., 2019).

Parallel analysis suggested a unidimensional factor solution. Based on low communalities (< 0.30), high cross-loadings, or redundancy in content, five items were excluded:

MBAQ_1: Prompt response when transaction fails
MBAQ_2: Clarity on transaction execution time
MBAQ_8: Time-saving compared to other channels
MBAQ_11: Requires little effort
MBAQ_13: Simplicity of mobile banking services

The final set included 10 items (MBAQ_3, MBAQ_4, MBAQ_5, MBAQ_6, MBAQ_7, MBAQ_9, MBAQ_10, MBAQ_12, MBAQ_14, MBAQ_15), all of which exhibited strong factor loadings (> 0.80) and collectively explained more than 76% of total variance.

Confirmatory Factor Analysis (CFA)

A Confirmatory Factor Analysis (CFA) was conducted to validate the factor structure using the maximum likelihood estimator with robust standard errors (MLR). The initial model demonstrated marginal fit:

- $\chi^2(35) = 299.69$, $p < .001$
- CFI = 0.919, TLI = 0.896
- RMSEA = 0.168 (90% CI: 0.151–0.186)
- SRMR = 0.034

According to Hu and Bentler (1999), recommended thresholds are CFI ≥ 0.95, TLI ≥ 0.95, RMSEA ≤ 0.06, and SRMR ≤ 0.08. Although SRMR was within acceptable limits, RMSEA and comparative fit indices indicated room for improvement. Based on modification indices, three residual covariances were added to improve model fit:

- MBAQ_14 ~~ MBAQ_15
- MBAQ_5 ~~ MBAQ_6
- MBAQ_3 ~~ MBAQ_4

The revised model showed significantly improved fit:

- $\chi^2(32) = 148.23$, $p < .001$
- CFI = 0.964, TLI = 0.950
- RMSEA = 0.117 (scaled RMSEA = 0.078)
- SRMR = 0.026

Although RMSEA remained slightly above the ideal threshold, the overall fit was acceptable, particularly considering the complexity of the model and sample size (Hooper et al., 2008).

5.3. Reliability and Validity Assessment of MBAQ scale

The internal consistency of the refined 10-item scale was assessed using Cronbach's alpha and Composite Reliability (CR). Both indicators confirmed excellent internal reliability:

- Cronbach's alpha = 0.97
- Composite Reliability (omega) = 0.97

Convergent validity was assessed using the Average Variance Extracted (AVE), 0.765, well above the minimum recommended value of 0.50. Additionally, all standardized factor loadings from the subsequent CFA ranged from 0.81 to 0.93, confirming that each item contributes strongly to the measurement of the latent construct.

Given the scale's unidimensionality, discriminant validity was not assessed using Fornell-Larcker (1981) or HTMT criteria (Henseler, Ringle, & Sarstedt, 2015), as no other constructs were modeled. Nevertheless, the high internal consistency and clear factor structure prove construct validity. These findings confirm that the final 10-item instrument is a valid and reliable measure of perceived mobile banking application quality.

5.4 Structural Model Results

To examine the proposed hypotheses, a structural equation model was estimated linking mobile application quality (MBAQ), satisfaction with mobile banking (NPS Mobile), and overall satisfaction and loyalty toward the bank (NPS Bank). The model demonstrated an excellent fit to the data, with all indices indicating a perfect match: CFI and TLI were 1.000, RMSEA and SRMR were 0.000. Given the model's just-identified structure (0 degrees of freedom), these values are expected.

The results revealed a significant positive effect of perceived mobile application quality on satisfaction with mobile banking ($\beta = 0.346$, $p < 0.001$), supporting hypothesis H1. Likewise, satisfaction with mobile banking strongly influenced bank-level satisfaction and loyalty ($\beta = 0.655$, $p < 0.001$), confirming hypothesis H2. However, the direct effect of app quality on overall bank loyalty was not statistically significant ($\beta = 0.060$, $p = 0.305$), suggesting that this relationship is primarily indirect.

The model explained 12% of the variance in NPS Mobile and 46% in NPS Bank, indicating good explanatory power for key constructs.

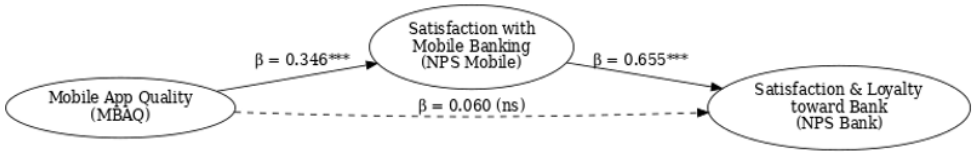

Figure 2. Structural Equation Model of the Effects of Mobile App Quality on Satisfaction and Loyalty Standardized path coefficients are shown. The dashed line indicates a non-significant direct effect Source: Author

A summary of path estimates and hypothesis testing is presented in **Table 6**.

Table 6. Summary of Structural Path Estimates and Mediation Effects

Hypothesis	Path	Std. Estimate (β)	SE	z-value	p-value	Significance
H1	MBAQ → NPS Mobile	0.346	0.015	3.95	< 0.001	Yes
H2	NPS Mobile → NPS Bank	0.655	0.065	11.196	< 0.001	Yes
Direct effect (c')	MBAQ → NPS Bank	0.06	0.011	1.026	0.305	No
Indirect effect (a*b)	MBAQ → NPS Mobile → NPS Bank	0.227	0.013	3.539	< 0.001	Yes
Total effect	MBAQ (total effect) → NPS Bank	0.287	0.016	3.598	< 0.001	Yes

Source: Author

5.5. Mediation Analysis

To evaluate the mediating role of satisfaction with mobile banking in the relationship between perceived app quality and bank-level loyalty, a bootstrap mediation analysis was conducted using 5,000 resamples. The results showed a statistically significant indirect effect ($\beta = 0.227$, $p < 0.001$), indicating that satisfaction with mobile banking mediates the relationship between app quality and bank-level loyalty.

The non-significant direct and significant indirect effects support the conclusion of complete mediation. This implies that the effect of app quality on customers' loyalty to the bank is channeled entirely through their satisfaction with mobile banking services. Table 6 also reports a detailed breakdown of direct, indirect, and total effects.

Bootstrap confidence intervals (BCa method) confirmed the robustness of the mediation effects. The indirect effect of mobile application quality on bank-level satisfaction and loyalty through satisfaction with mobile banking was statistically significant ($\beta = 0.227$, 95% CI [0.023, 0.074], $p < .001$). The direct effect of app quality on bank NPS remained non-significant ($\beta = 0.060$, 95% CI [–0.008, 0.036], $p = .296$), confirming a complete mediation structure. The total effect was statistically significant ($\beta = 0.287$, 95% CI [0.027, 0.088], $p < .001$), indicating that application quality ultimately contributes to bank-level loyalty through its impact on mobile satisfaction.

5.6. Multigroup Structural Equation Modeling (Multigroup SEM)

To assess whether the relationships proposed in the mediation model differ across key respondent subgroups, a multigroup SEM approach was employed using the lavaan package in R. This method was applied to compare structural paths across:

- Age groups

- Education levels
- Usage frequency of mobile banking functions, including balance checking and funds transfer.

For each moderator variable, two models were estimated and compared:

- Unrestricted model: All structural path coefficients were freely estimated for each group.
- Restricted model: Structural path coefficients were constrained to be equal across groups.

A chi-square difference (likelihood ratio test) was conducted to determine whether the equality constraints significantly worsened model fit. A significant result indicated that at least one of the hypothesized relationships varies across the examined subgroups, highlighting the presence of moderation effects.

This approach allowed for identifying segment-specific patterns in how users perceive mobile application quality and its impact on satisfaction and loyalty.

5.6.1. Group Differences by Age: Multigroup SEM Analysis

The multigroup SEM analysis revealed a statistically significant difference in structural paths across the four age categories ($\Delta\chi^2 = 21.917$, df = 9, p = 0.009). Figure 3 presents the standardized path coefficients for each group.

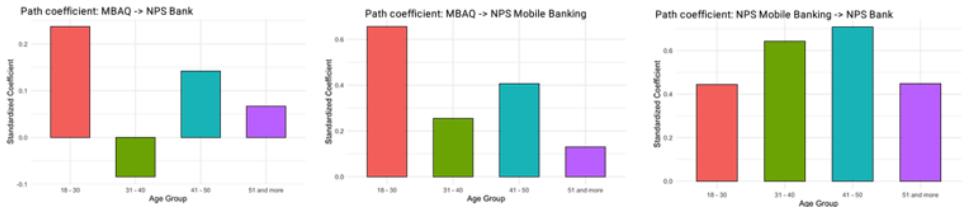

Figure 3. Differences in Standardized Coefficient by Age
Source: Author

5.6.2. Group Differences by Education: Multigroup SEM Analysis

A statistically significant difference was found across the three education groups ($\Delta\chi^2 = 12.706$, df = 6, p = 0.048). The standardized path coefficients are shown in Table 7.

Table 7. Standardized SEM Coefficients by Education Level

Path	Bachelor's degree	Master's or Doctoral degree	Secondary school or lower education
MBAQ → nps_mobile_banking	0.364	0.449	0.134

nps_mobile_banking → nps_bank	0.597	0.703	0.785
MBAQ → nps_bank	0.010	0.191	0.181

Source: Author

5.6.3. Group Differences by M-Banking Payment Frequency: Multigroup SEM Analysis

Significant differences were found across the five m-banking payment frequency groups ($\Delta\chi^2$ = 28.62, df = 12, p = 0.004). The standardized path coefficients are presented in Table 8.

Table 8. Standardized SEM Coefficients by M-banking Payment Frequency Group

Path	Daily	Monthly	Weekly	Never	Several times a year
MBAQ → nps_mobile_banking	0.177	0.575	0.455	0.443	0.115
nps_mobile_banking → nps_bank	0.699	0.686	0.461	0.428	0.787
MBAQ → nps_bank	0.003	0.209	0.028	0.078	0.039

Source: Author

6. Discussion

This study investigated the relationships between perceived mobile banking application quality, satisfaction with mobile banking services, and overall satisfaction and loyalty toward the bank. Three research questions addressing direct and mediated effects within the proposed conceptual model guided the analysis.

In response to RQ1, the findings confirmed that the perceived quality of the mobile banking application has a statistically significant and positive effect on user satisfaction with mobile banking services, as measured via the mobile-specific Net Promoter Score (β = 0.346, p < 0.001). The model explained approximately 12% of the variance in satisfaction, indicating that while mobile app quality is an important predictor, other factors may also contribute to shaping user evaluations. The mobile banking application quality scale (MBAQ), developed for this study, captured key dimensions of digital service delivery, including security, trust, usability, transaction speed, navigability, information accessibility, and simplicity. Items such as "The mobile banking service is exactly as promised" and "All my transactions made through the mobile banking app are secure" reflect reliability and trust. At the same time, "It is easy to navigate the mobile banking app" and "Using mobile banking, it is easy to do what I want to do" tap into the system's efficiency and functional clarity. These findings support the premise that well-designed, secure, and user-friendly mobile applications enhance customers' digital

experiences and foster satisfaction. However, the relatively modest explained variance suggests that additional drivers of satisfaction, such as transaction fees, perceived value, customer support availability, personalization features, and network stability, may also play significant roles. These elements were not included in the current model but represent meaningful directions for future research to develop a more comprehensive understanding of satisfaction in mobile banking environments.

Regarding RQ2, results showed that satisfaction with mobile banking services strongly and significantly influences customers' satisfaction and loyalty toward the bank ($\beta = 0.655$, $p < 0.001$). This highlights the critical role of digital touchpoints in shaping customers' broader perceptions of their banking institution, confirming that mobile app experiences are not isolated but integrated into holistic brand evaluations.

Addressing RQ3, the mediation analysis revealed that satisfaction with mobile banking fully mediates the relationship between application quality and bank-level loyalty. The indirect effect ($\beta = 0.227$, $p < 0.001$; 95% CI \[0.023, 0.074]) was significant, while the direct effect of app quality on bank NPS was not ($\beta = 0.060$, $p = 0.296$; 95% CI \[−0.008, 0.036]). These results suggest that the impact of mobile app quality on loyalty is not immediate but is transmitted through improved satisfaction with the mobile service channel. The total effect ($\beta = 0.287$, $p < 0.001$) confirms that app quality contributes meaningfully to overall customer loyalty, but only when satisfaction with the mobile banking experience is accounted for.

In addition to structural relationships, descriptive statistics revealed that users rated mobile banking app quality positively, with an overall mean score of 39.2 out of a maximum of 50. Mobile NPS ($M = 8.75$, $SD = 1.66$) and bank NPS ($M = 8.17$, $SD = 1.84$) were also relatively high, indicating favorable customer attitudes across institutions. Notably, loyalty levels varied by bank, with Adicco and Sparkasse achieving the highest app satisfaction and NPS scores.

Furthermore, multigroup SEM analyses provided insights into how user characteristics moderate the observed relationships. Age-based differences revealed a statistically significant variation in structural paths ($\Delta\chi^2 = 21.917$, $df = 9$, $p = 0.009$). The strength of the relationship between mobile app quality and satisfaction with mobile banking (MBAQ → NPS Mobile) was highest among the youngest users (18–30: $\beta = 0.656$) and among users aged 41–50 ($\beta = 0.406$), while it was weakest among users aged 51 and above ($\beta = 0.130$). This indicates that older customers may rely on factors other than technical usability when forming satisfaction judgments. The path from satisfaction with mobile banking to bank loyalty (NPS Mobile Banking → NPS Bank) was strong across groups but most pronounced in the 41–50 segment ($\beta = 0.709$). In contrast, it was relatively weaker in the youngest group ($\beta = 0.444$), potentially due to lower brand attachment.

Education-based differences were also statistically significant ($\Delta\chi^2 = 12.706$, $df = 6$, $p = 0.048$). Respondents with a Master's or Doctoral degree demonstrated the strongest path from MBAQ to NPS Mobile ($\beta = 0.449$), followed by Bachelor's degree

holders (β = 0.364), and lastly users with secondary education or lower (β = 0.134). Conversely, the link from mobile satisfaction to bank loyalty was strongest among users with the lowest education (β = 0.785), suggesting that direct experiential satisfaction more heavily influences loyalty in this segment.

Differences based on m-banking payment frequency were also significant ($\Delta\chi^2$ = 28.62, df = 12, p = 0.004). The MBAQ → NPS Mobile path was strongest among monthly users (β = 0.575), followed by weekly (β = 0.455), while it was lowest among daily (β = 0.177) and occasional users (β = 0.115). Interestingly, satisfaction with mobile banking had the most substantial impact on bank loyalty among users who only used the app several times per year (β = 0.787), suggesting that infrequent users may develop strong brand attachment when satisfied, possibly due to lower expectations. Given that most users in the sample engage in monthly payments via mobile banking, banks must optimize the app experience around this everyday use case. Targeted feature enhancements, contextual communication, and reminders tailored to monthly users could yield the most excellent satisfaction and loyalty returns. Simultaneously, banks may explore strategies to elevate engagement among daily and occasional users through personalization, gamification, or value-added services.

In contrast, the analysis by balance-checking frequency did not yield statistically significant differences ($\Delta\chi^2$ = 11.44, df = 9, p = 0.247), indicating that this behavior does not moderate the mediation structure.

Together, these multigroup findings emphasize the importance of user segmentation when designing mobile banking services and experiences. Age, education, and transactional frequency meaningfully shape how users perceive, evaluate, and respond to mobile banking experiences. Designing strategies that align with each segment's unique expectations can enhance satisfaction, engagement, and long-term loyalty.

7. Conclusion, Limitations, and Future Research Directions

7.1 Conclusion

This study examined how the perceived quality of mobile banking applications influences customer satisfaction with mobile banking services and, in turn, satisfaction and loyalty toward the bank as a whole. Drawing on service quality, customer satisfaction, and digital loyalty theories, a structural equation model was developed and tested using data from 267 active mobile banking users in Bosnia and Herzegovina. The results confirmed that mobile app quality significantly affects satisfaction with mobile banking (β = 0.346, p < 0.001), and that this satisfaction fully mediates the relationship between app quality and overall loyalty toward the bank (indirect effect β = 0.227, p < 0.001). The direct effect of app quality on loyalty was not statistically significant (β = 0.060, p = 0.296), supporting the complete mediation structure. The total effect (β = 0.287, p < 0.001) suggests that app quality improves loyalty through improved satisfaction.

The validated Mobile Banking Application Quality (MBAQ) scale, comprising ten refined items, captured core dimensions such as usability, security, clarity, and reliability. The model explained 12% of the variance in mobile banking satisfaction and 46% in bank loyalty.

Multigroup SEM analyses revealed that age, education level, and m-banking payment frequency significantly moderated structural relationships, while balance-checking frequency did not. Younger and more educated users were more responsive to app quality, while less frequent users of payment features showed stronger loyalty responses when satisfied. These insights emphasize the importance of user segmentation in digital strategy.

Overall, the study highlights the strategic role of mobile service quality in fostering satisfaction and loyalty. For banks, investing in user-centric mobile experiences is critical for maintaining competitive advantage in an increasingly digitalized service environment.

7.2 Limitations

Despite its contributions, this study has several limitations. First, it employed a cross-sectional and self-reported survey design, limiting causal inference. Future research should consider longitudinal or experimental designs to confirm temporal dynamics. Second, the study was geographically confined to Bosnia and Herzegovina, which may limit generalizability to other markets with different digital maturity, expectations, or regulatory conditions. Third, although the model focused on app quality, it omitted other possible antecedents of satisfaction, such as perceived value, service responsiveness, pricing transparency, or brand trust. These factors may explain additional variance in satisfaction, which reached only 12% in the model. Fourth, satisfaction and loyalty were measured using single-item Net Promoter Score (NPS) measures. While widely adopted, single-item scales may lack the nuance of multi-item instruments such as Customer Satisfaction Score (CSAT) or Customer Effort Score (CES).

7.3 Recommendations for Future Research

Future research can build on these findings by:

- Expanding the conceptual model to include broader drivers of satisfaction, such as personalization, pricing fairness, and digital trust.
- Examining additional moderating variables, such as digital literacy, technology anxiety, and length of the banking relationship.
- Conducting comparative cross-country analyses to identify cultural or institutional effects on mobile service perceptions.
- Using mixed-methods approaches that combine survey data with qualitative user interviews or usability testing to explore deeper behavioral mechanisms.

- Leveraging longitudinal or behavioral tracking data (e.g., app usage logs) to assess how mobile experiences evolve and affect loyalty.

By addressing these directions, future studies can offer richer, more generalizable insights into the digital customer experience and inform better decision-making in financial service innovation.

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Appendix A

MBAQ (Mobile Banking Application Quality) Scale: Full Item List and Selected Indicators

The initial scale designed to measure perceived quality of mobile banking applications consisted of 15 items. Based on exploratory factor analysis, 10 items (shown in bold) were selected for the final model estimation. Each item was rated on a 5-point Likert scale (1 = Strongly disagree, 5 = Strongly agree).
MBAQ_1: My mobile banking app provides prompt responses if my transaction is not processed.
MBAQ_2: I know exactly when my transaction will be performed.
MBAQ_3: The mobile banking app service is exactly as promised.
MBAQ_4: The mobile banking transaction history is easily accessible and well-organized.
MBAQ_5: I have full trust in my bank's mobile banking services.
MBAQ_6: All my transactions made through the mobile banking app are secure.
MBAQ_7: Mobile banking app allows me to complete transactions quickly.
MBAQ_8: Using mobile banking app saves time compared to going to branch.
MBAQ_9: It is easy to obtain additional information related to the mobile banking service.
MBAQ_10: It is easy to navigate mobile banking app.
MBAQ_11: Using mobile banking app does not require lot's of efforts.
MBAQ_12: The mobile banking registration process is simple.
MBAQ_13: The mobile banking service is very easy to use.
MBAQ_14: Using mobile banking it is easy to do what I want to do, for example transferring funds from my account to any other account, bill payments, etc.
MBAQ_15: The mobile banking service itself is clear and simple.
Note: Items in italics were excluded due to low communalities, high cross-loadings, or redundancy in conceptual content. The selected 10 items demonstrated high factor loadings and strong internal consistency, supporting the scale's validity.

Effectiveness of forensic accounting in bankruptcy proceedings on the capital balance sheet position

Jagoda Osmancevic[1*], Senada Kurtanovic[1] and Edina Sehic[2]

[1] Faculty of Economics at the University of Bihac, Bihac, B&H
[2] Commercial and Investment Bank Ltd, Velika Kladusa, B&H

E-mail: jagoda.osmancevic@unbi.ba

Abstract. Bankruptcy proceedings in public and professional rhetoric are often equated with the necessary winding down of an insolvent legal entity, although its primary purpose implies a legally regulated process that seeks to achieve an even and fair collection of the claims of all creditors, while minimizing the negative impact on the wider economic system. Initiation of bankruptcy proceedings can be initiated by the debtor himself or his creditors, after which the bankruptcy court decides on the initiation of preliminary proceedings in order to determine the existence of legal conditions for opening bankruptcy. At that stage, three procedural options are possible: acceptance of a third party's statement about taking over the debt, opening the possibility for forced settlement, or appointing an expert - a bankruptcy administrator, for the purpose of assessing the debtor's financial condition, except in cases where the conditions for opening bankruptcy are obvious. In practice, one of the key problems is the existence of out-of-date or manipulated financial documentation, which makes it difficult to precisely determine the debtor's real economic position. In this context, forensic accounting emerges as an important instrument in the function of transparency and protection of the interests of bankruptcy participants. The aim of this paper is to analyse the role and effectiveness of forensic accounting in the bankruptcy proceedings, with a special emphasis on the identification of irregularities, protection of the balance sheet position of capital and ensuring the timely action of creditors and capital owners. The research points to the need for greater institutional integration of forensic mechanisms into bankruptcy practices in order to improve the efficiency and fairness of the procedure.

1. Introduction

Forensic accounting is a specialized branch of accounting focused on the collection, analysis and evaluation of financial data in order to detect fraud, abuse and other forms of financial irregularities. Its role within the bankruptcy procedure is gaining special importance, because it enables a detailed insight into the actual financial situation of

the debtor, and the identification of potential irregularities that can significantly affect the fair distribution of assets among creditors.

Special attention in this work is devoted to the analysis of the balance sheet position of the capital as a key indicator of the financial stability and solvency of the business entity. In this context, it is investigated how much the forensic accounting approach contributes to the transparency and fairness of the bankruptcy procedure, as well as what are the challenges of its practical application.

In practice, non-up-to-date or selective bookkeeping can lead to a situation where the financial statements show assets that actually no longer exist, due to previous sales or seizures. Such reporting can lead to the bankruptcy judge and creditors being misinformed, which undermines trust and the efficiency of the entire procedure. When creditors have accurate and reliable information about the real possibility of collecting their claims, they are able to adjust their business decisions in time and minimize negative consequences.

Based on the above, the following research hypothesis was set:
"The application of forensic accounting significantly contributes to the efficiency of bankruptcy proceedings through the precise determination of the balance sheet position of capital, which results in better protection of the interests of creditors and capital owners."

2. Theoretical framework of the research

2.1 Capital Misuse in Limited Liability Companies: Forensic Accounting and Legal Framework in the Context of Bankruptcy Proceedings

A limited liability company (d.o.o.) is a form of business entity in which the company is solely responsible for the obligations of the company with its assets. This legal construction protects the personal property of company members (owners), but at the same time imposes a clear distinction between the company's property and the property of its founders. At the moment of entering shares in things and rights into the company - as stipulated in Article 307 of the Law on Business Companies of the Federation of Bosnia and Herzegovina - the owner ceases to be the owner of that property; it becomes the property of a legal entity, i.e. company. For example, if the founder enters real estate as a non-monetary contribution to the share capital, that real estate must be transferred to the company and entered in the land register as an asset of the business entity. Any use of that property by the founder after the entry, without a formally contracted relationship, is considered the use of someone else's property - that is, the provision of a service by the company to its member. The Law on Business Companies of the Federation of Bosnia and Herzegovina additionally emphasizes the difference between the owner and the company using the term "member of the company", which legally and terminologically insists on their separation. However, in practice it often happens that company owners do not respect this separation.

Phenomena such as "internal deletion" of capital, without implementing the prescribed procedure, represent an attempt to illegally recover property from the company. In bankruptcy proceedings, such actions are subject to rebuttal because they directly threaten the rights of creditors.

The reduction of the basic capital is regulated by Article 349 - 352 of the Law on Business Companies of the Federation of Bosnia and Herzegovina, which stipulates that the decision on the reduction must be made by the members of the company, submitted to the competent court and published in the "Official Gazette of the Federation of Bosnia and Herzegovina", which calls on creditors to report their claims. Only after the expiration of the legal term and after settlement or insurance of claims, it is possible to enter the capital change in the court register in accordance with Article 307 of the same Act. Bypassing this procedure – e.g. by deregistering the real estate from the company's books based on the founder's internal decision - seriously endangers the assets available to creditors and directly violates the principles of legal certainty. Such actions can be contested in bankruptcy proceedings as illegal, in accordance with Articles 139-146 of the Law on Bankruptcy of the Federation of Bosnia and Herzegovina.

The role of forensic accounting is to identify suspicious transactions through a detailed review of the structure and changes in capital, especially those that may be an attempt to avoid obligations to creditors. Horizontal and vertical analysis of capital, combined with examination of supporting documentation (decisions, entries in registers, land registers), is the basis for identifying manipulations of the capital structure. As stated by Wells (2017), manipulations of the capital structure – especially unannounced changes in the ownership role, transfers of assets without a market basis and reduction of capital without a legal procedure – are frequent indicators of attempts to avoid obligations on the eve of bankruptcy proceedings. Additionally, the forensic expert should also pay attention to the owner's loans to the company. When the owner grants a loan to the company instead of increasing the capital, in case of bankruptcy his claim is subject to a lower order of payment (usually after all separate and general creditors). That is why it is important to analyse:

- when the loan is recorded,
- whether and how it was returned,
- whether the terms of the loan were marketable,
- whether the loan disguised the actual capital investment.

Such transactions can be grounds for doubting the intentions of the founder, especially if the loan was repaid immediately before the opening of bankruptcy proceedings.

In conclusion, the aforementioned possible forms of misuse of capital are summarized in the following table.

Table 1. Possible forms of misuse of capital with appropriate forensic indicators

Form of misuse of capital	Forensic indicators	Legal references

Internal deletion of capital	Non-compliance with the legal procedure of capital reduction, lack of public announcement	Law on Business Companies of the Federation of Bosnia and Herzegovina, Article 349 – 352
Transfer of assets from the company without compensation	Transfer of assets without commercial basis, lack of transaction documentation	Law on Bankruptcy of the Federation of Bosnia and Herzegovina, Articles 139 – 146
Manipulation of the capital structure	Drastic changes in capital composition, unannounced property transfers	Law on Bankruptcy of the Federation of Bosnia and Herzegovina, Articles 139 – 146
Owner loans to the company	Loans that are not in line with the market, unspecified repayments, manipulation of balance sheets	Law on Bankruptcy of the Federation of Bosnia and Herzegovina, Articles 139 – 146

(Source: processed by the authors.)

2.2 Forensic accounting as a tool in detecting profit manipulation in bankruptcy proceedings

The scope of forensic accounting as a specialized accounting discipline includes a number of activities that are of key importance for detecting irregularities and fraud in financial reporting, especially in situations where bankruptcy proceedings have been initiated against a business entity. In this context, forensic accounting is a useful tool for the temporary and permanent bankruptcy administrator, especially when identifying and proving legal and financial actions aimed at extracting assets from the assets of the bankrupt debtor, through the unethical application of creative accounting. Creative accounting is the application of various accounting methods and estimates that aim to present financial results (profit) in a more favorable light, often by making accounting decisions that are technically legal, but may be unconscionable or manipulative.

The motives for applying creative accounting to the profit item within the balance sheet position of capital, which is most susceptible to "imperceptible" influence by the founder or manager, are different. They can be: increasing the company's attractiveness for investors, creditors or potential partners, achieving bonuses and awards related to financial results, optimizing tax obligations by showing lower or higher profits, managing the perception of stability and business success, and the like. The main techniques and procedures of creative accounting that affect profit are: redistribution of income and expenses, such as postponing the recognition of income or accelerating the recognition of costs, then the application of estimated values, which refer to the manipulation of reserves, depreciation or assessment of receivables. For example, a change in depreciation policy can significantly affect the result. Also, the consolidation and grouping of items, that is, the inclusion or omission of certain items that change the

total profit and changes in accounting policies, which primarily relate to the choice of inventory valuation method (WAC, FIFO) or revenue recognition, are included in the mentioned techniques and procedures. The consequences of creative profit accounting can be different. An increase or decrease in the reported profit without a real change in the business results, can lead in the short term, if discovered, to the loss of confidence of investors and regulators. In the long run, discovered or not, it can damage the financial stability of the company. Creative accounting often relies on "gray zones" within the legal framework, and balances between permitted and ethically questionable, which is why it is increasingly analyzed in the context of corporate governance and ethics (Rezaee, Z., 2009).

According to the Bankruptcy Law of the Federation of Bosnia and Herzegovina, the bankruptcy administrator has a legal obligation to carefully examine all legal and financial actions of the debtor that were undertaken in the period before the opening of bankruptcy proceedings, and which could be subject to rebuttal in accordance with Articles 139-146 of the same Law. In this sense, a forensic approach to the analysis of the profit balance position can reveal indicators of manipulative behavior, especially if significant profits were reported in previous periods, which were then withdrawn through dividend payments, unpaid loans, fictitious costs or other means of covert extraction of value from the company. A forensic accountant in bankruptcy proceedings should:

- Analyze profit payments in detail - with special emphasis on the time of payment, the basis (decision of the assembly), the method of payment and possible return flows of money to the company.
- Examine the consistency of the accounting policy - to determine if, and when, there was a change in the method of valuation of inventory, income or depreciation, and for what purpose this was done.
- Compare balance sheet positions with external records - including tax returns, bank statements and records of the Tax Administration of the Federation of Bosnia and Herzegovina, in order to confirm the credibility of the presented results.

The following table systematizes possible forms of profit manipulation and forensic indicators in the context of bankruptcy proceedings.

Table 2. Possible forms of profit manipulation and forensic indicators in the context of bankruptcy proceedings

Form of manipulation	Applied technique	Forensic indicator	Possible legal consequences in bankruptcy
Revenue overstatement	Revenue recognition prior to delivery /	Revenues grow rapidly without commensurate	Possible rebuttal of legal actions; responsibility for

	from fictitious transactions	increase in cash flow or inventory	fraudulent business bookkeeping
Underestimation of expenses	Postponement of expenses / non-recognition of liabilities	Net profit disproportionately high compared to the industry average	Increase in liabilities to bankruptcy creditors
Change in accounting policies	Change in method of depreciation, inventory (WAC to FIFO) without economic justification	Policy changes occur immediately before bankruptcy	Manipulative reporting - possible expert testimony and criminal liability
Allocation of reserves	Reduction of provisions for future obligations (e.g. severance pay, guarantees)	Sudden drop in reserves without changing the business model or risk	Return of unjustified distributed profits to the bankruptcy estate
Internal profit payment	Payment of profit to the management or owners in the months preceding the opening of bankruptcy	Net profit paid even though a loss occurs later, with minimal cash reserves	Refusal of legal actions that disrupt the equal settlement of creditors or represent favouritism to individual creditors in accordance with Articles 139 - 140 of the Bankruptcy Law
Consolidation of items	Inclusion/exclusion of certain transactions from the balance sheet	Comparison of individual and consolidated statements reveals illogicality's	Suspicion of concealment of related parties and transfer of losses

(Source: processed by the authors.)

If major irregularities are observed in the sense that in the previous period a positive financial result of the business was achieved, which caused the creation of accumulated profit, and then the company fell into financial difficulties, it is necessary

to make a more detailed analysis in terms of revealing the manipulation of income (possible overestimation) as well as expenses (in the sense of their underestimation). The most common way of "falsifying statements" in financial statements is through the manipulation of income and expenses, whether overstatement or understatement is used. When the company aims to show higher revenues, it mainly uses the following techniques: recognition in the current period of revenues that relate to the future period, recognition of revenues in a higher value than the same amounts, recognition of fictitious revenues, and recognition of revenues before the customer accepts delivery and recognition of revenues when the customer's payment is uncertain. Showing a higher profit of the company can also be achieved by showing expenses in a smaller amount than they were actually incurred using the following methods: leaving the expenses of the current period for recognition in the future period, not recognizing the expenses actually incurred and recognizing the expenses in a lower value than the one in which they were actually incurred.

The issue of revenue is regulated by International Financial Reporting Standard 15 (IFRS 15) – Revenue from contracts with customers. It prescribes the principles that the company should apply when reporting regarding the type, amount, time frame and uncertainty of income. The basic principle of revenue recognition according to IFRS 15 is elaborated through a five-step model:

1. Determination of the contract with the customer

The first step is to determine whether IFRS 15 applies to the contract in question. The entity should apply this Standard to all contracts with customers, except for lease agreements from the scope of IFRS 16 - Leases, insurance contracts from the scope of IFRS 4 - Insurance contracts, financial instruments and other contractual rights or obligations from the scope of IFRS 9 - Financial Instruments, IFRS 10 - Consolidated Financial Statements, IFRS 11 - Joint Arrangements and IAS 27 – Separate financial statements and IAS 28 – Investments in associates and joint ventures and non-monetary exchanges between entities performing the same business activity to facilitate sales to customers or potential customers.

2. Identification of individual obligations in the contract

It is necessary to identify each promised transfer to the customer, i.e. the obligation we took on for a specific job, and for the purpose of determining and reporting income for each individual obligation, i.e. for each part of the work that was agreed, taking into account the moment of recognition of income for each individually performed obligation.

3. Determining the price of the transaction

The transaction price is the amount of consideration to which the entity expects to be entitled in exchange for the transfer of the promised goods or services to the customer, excluding amounts collected on behalf of third parties (for example, certain sales taxes).

4. Allocation of the transaction price to individual obligations in the contract

The income should be distributed and presented according to the contracted, individual obligations. For example, the subject must separately report the income from the delivery of a product in relation to the income from the service provided, when it provides such a role in a package with the product.

5. Recognition of income as the entity fulfils its performance obligation

An entity should recognize revenue when (or to the extent that) the entity fulfils the performance obligation by transferring the promised good or service (i.e., the asset) to the customer. Assets are transferred when (or to the extent that) the buyer acquires control over the asset.

Forensic analysis can determine that profits were previously "inflated" through strategies such as fictitious revenue recognition, deferral of expenses, or manipulation of accounting estimates. By applying IFRS 15 – Revenue from contracts with customers, the forensic expert must assess whether revenue recognition has been performed in accordance with the five-phase model of that standard. Any deviation from the rules of revenue recognition in the sense of premature or unjustified recording may indicate an attempt to embellish the company's financial picture. Thus, the scope of forensic accounting as a discipline is diverse. Includes:

1. internal investigations of a company - unlike an auditor who, due to significant inconsistencies in the information in the financial statements, expresses an opinion (negative, reserved opinion or can refrain from an opinion), a forensic accountant, if he discovers a fraud, must first investigate it and call to account the persons who in any way led to this fraud;
2. participation in court cases - the forensic accountant appears in the role of a consultant, provides financial expert services, and may be appointed by the court as an expert for expert testimony;
3. providing assistance in criminal cases - forensic accountants detect, evaluate and report to the authorities in the business entity about business transactions related to fraud, embezzlement and other criminal acts;
4. assistance in solving problems related to insurance claims - a forensic accountant assesses the justification of the claim, the amount of damage and the amount of claims based on the claim;
5. government sector - forensic accounting also benefits the state administration in a way that it ensures compliance with appropriate legal regulations or by participating in public investigations in various cases.

Therefore, forensic accounting is not only a tool for retrospective analysis of business, but also a means of protecting the interests of creditors by identifying actions that can be grounds for rebuttal under the Bankruptcy Act. In conclusion, forensic accounting, through the multidisciplinary application of accounting, legal and audit knowledge, provides a reliable basis for evaluating the legality and reality of profit as a balance sheet position. His role in the bankruptcy procedure becomes crucial when there is an indication that the legal form of the company was used to conceal the true intentions -

reducing obligations to creditors and extracting funds from the business entity immediately before or during the bankruptcy procedure.

2.3 Analytical techniques in forensic accounting

Analytical techniques are used to analyse the relationship between individual items in financial statements, and then move on to the analysis of business transactions. In the literature, relationship analysis, vertical data analysis and horizontal data analysis are most often mentioned.

Relationship analysis is based on the analysis of different relationships in relation to individual balance sheet positions, which are carriers of different information about the financial position and the achieved business result, and are used for making business decisions. Depending on which decisions need to be made, we distinguish several groups of financial indicators, namely: liquidity indicators, which measure the company's ability to meet its due short-term obligations, indebtedness indicators, which measure how much the company is financed from other sources of funds, activity indicators, which measure how efficiently the company uses its resources, economic indicators, which measure the ratio of income and expenses, i.e. they show how much income is generated per unit of income, profitability indicators, which measure the return on invested capital, which is considered the highest management effectiveness, and investment indicators, which measure the success of investments in ordinary shares (Zager K. et. al., 2008). Indicators of liquidity and indebtedness are considered indicators of business safety, while indicators of economy, profitability and investment are indicators of business success. Activity indicators are considered both safety indicators and business success indicators.

Calculating indicators alone does not provide adequate information for decision-making, so the results of the analysis must be compared with certain standard values, such as, for example, planned results, the movement of the size of a certain indicator in a certain period of time in that company, the movement of that indicator in another company engaged in the same activity, and the like. While managers, investors and creditors look optimistically at the increase in indicators, a forensic accountant observes and interprets the obtained results of relationship analysis differently.

Table 3. Interpretation of the results obtained

Results of relationship analysis	Interpretation of results viewed from the perspective of a forensic accountant
Recorded continuous growth of indicators of the success and safety of a certain company's operations in periods of economic stagnation, while competing companies are lagging behind.	There is doubt as to the accuracy of the data presented in the financial statements.

Increase in productivity indicators, without significant investment and activities that would contribute to this.	There are doubts regarding the proper registration of workers, declaration of obligations towards workers and the state.
Continuous growth of indicators of economy and profitability.	The possibility of editing accounting data on the income, costs and expenses of the company

(Source: adapted by the authors according to Isakovic-Kaplan S., 2021).

The forensic accountant should observe the calculated business indicators in the context of the specifics and circumstances in which the company itself operates. If it is a company that operates in different countries, the different legislation and regulations of those countries should be taken into account. Likewise, the change of one quantity used in the calculation of the indicator conditions a different interpretation of the result of the given indicator. The application of different accounting policies (e.g. inventory valuation) also affects the interpretation of financial figures and calculated indicators. Forensic accountants do not stop at the calculation of indicators and do not analyse the results like other analysts. His work should be based on forming individual indicators or a group of indicators based on data from financial statements that will provide a basis for proving or refuting suspicions of accounting manipulation procedures.

One of the most commonly used models for exposing the manipulative behaviour of a company in the area of financial results is the model of professor Messod D. Beneish (Isakovic-Kaplan S., 2022). Beneish's M-score model is a mathematical model that uses a comparison of individual indicators in the current period (t) compared to the previous period (t-1).

Vertical data analysis or structure analysis breaks down the composition of financial statements, on the basis of which an insight into the relationship and ratio of individual items is obtained. This shows the share (%) of each balance sheet position in relation to the base value, which is determined depending on the type of financial statement. Thus, in the balance sheet, total assets are assigned a base value of 100%, and other asset items are expressed as percentage values in relation to total assets. The total liability is also assigned a base value of 100%, so the percentage of participation of other liability items is recalculated in relation to the base value. When analysing the income statement, the base value is business income. An overview of the tabular presentation facilitates the analysis of the structure of the balance sheet positions and the detection of irregularities in their movements. An example of a tabular presentation of vertical data analysis follows below, and it can be adapted depending on the case by case.

Table 4. Table design proposal for vertical analysis

Description of the position	Amount of the item in the financial statement in the observed period	Percentage participation of the item in the observed period in relation to the base value

(Source: adapted by the authors according to Isakovic-Kaplan S., 2021).

With the profit and loss account, vertical analysis looks at the quality of the business result, as well as possible manipulations with income and expenses. Applying it to the income statement, this method provides insight into the quality of assets as well as the source of these assets, and narrows the search area for committed fraud.

Horizontal analysis is performed by comparing items from the current period with the same items from the previous period(s), with the aim of monitoring sudden changes, declines or increases in the amount of individual item positions in the financial statements. The current business period is used as the base, so changes in the value of items in the financial statements in the previous period are observed in relation to the base values of those items. If more than two periods are compared, changes in each business period are calculated and expressed in relation to the period preceding it. Differences between the base period and the period with which it is compared can be expressed in absolute amounts and/or in percentage terms. In the literature, it is also called trend analysis or dynamic analysis, which evaluates the tendency of items from financial statements by observing changes during at least two consecutive periods.

A suitable tabular overview can be a source of information when the same financial statement items are presented side by side for two or more years. The simplest case is the comparison of two business periods, and in that case the example of the tabular presentation below can be used. Of course, this kind of display can also be used when comparing several periods, with the addition of the necessary additional columns.

3. Analysis of capital and profit manipulation in bankruptcy proceedings – case study

Analytical techniques presented in the previous chapter are not only used for general financial diagnostics, but have an extremely important role in detecting targeted manipulations before the opening of bankruptcy proceedings. Through horizontal and vertical analysis, as well as analysis of financial indicators, it is possible to identify unusual patterns of behaviour in connection with profit payments, changes in the capital structure, or transferred funds that do not reflect the real state of business.

Such patterns may indicate the existence of legal actions that disrupt the equal settlement of creditors, i.e. putting individual creditors or owners in a more favourable position, which according to the current Bankruptcy Law of the Federation of Bosnia and Herzegovina, is subject to rebuttal in terms of Articles 139 - 146. In this context, the

forensic accountant uses analytical techniques as instruments for testing the credibility of financial statements and the legality of key transactions that precede bankruptcy.

In the continuation of the paper, an analysis of the most common form of manipulation in the balance sheet of capital and profit is presented, through a case study - Bankruptcy debtor D, with a special focus on motives, accounting procedures and indicators that point to possible illegal or harmful actions for the bankruptcy estate.

Bankruptcy debtor D (hereinafter: Company D) was founded as a limited liability company, whose main activity is the production of other building joinery and elements. The contracted and paid capital amounted to 234,738.00 KM. The Company has one member (a physical person), who is a related person (marital partner) of the Company's director. The proposal to open bankruptcy proceedings was submitted in April 20XX year. Since it was not possible to determine with certainty whether there are reasons for opening bankruptcy proceedings, the competent bankruptcy judge issued a Decision on the initiation of previous bankruptcy proceedings and appointed a temporary bankruptcy administrator. On the day of delivery of the Decision on the initiation of previous bankruptcy proceedings, the period of 30 days for the temporary bankruptcy administrator to exercise the rights, obligations and submit reports defined by the Bankruptcy Law began to run.

The temporary bankruptcy administrator begins with the determination of the company's assets by arriving at the headquarters, and by inspecting public registers and bookkeeping documentation. Arriving at the address registered as the place of the company's headquarters in the competent court register, it was established that it is the place of residence of the company's owner and director. Next to the family house, there is a carpentry workshop, which was included in the Company's capital. From the submitted financial statements, analysing the five previous years from the date of submission of the proposal to open bankruptcy, the company had the following values in the balance sheet.

Table 5. Balance sheet of Company D for the period $20XX_{-4}$ – 20XX (in 000 KM)

Description of balance sheet position	Assets				
	$20XX_{-4}$	$20XX_{-3}$	$20XX_{-2}$	$20XX_{-1}$	20XX
Real estate, facility and equipment	110	86	0	0	0
Loss in excess of capital	182	220	308	308	308
Total assets	290	306	308	308	308
Description of balance sheet position	Capital and liabilities				

	20XX-4	20XX-3	20XX-2	20XX-1	20XX
Capital	308	308	228	228	228
Loss of earlier years	(308)	(308)	(228)	(228)	(228)
Long-term loans	52	54	54	54	54
Obligations based on wages and salary benefits	200	214	216	216	216
Other short-term liabilities	20	20	20	20	20
Obligations for other taxes and other duties	2	2	2	2	2
Accrued costs and deferred revenues	16	16	16	16	16
Total capital and liabilities	290	308	308	308	308

(Source: Report of the temporary bankruptcy administrator of Company D, based on data from the financial statements of Company D).

The temporary bankruptcy administrator used horizontal analysis when reviewing the financial statements. As a reminder, this analysis is performed by comparing items from the current period with the same items from the previous period(s), with the aim of monitoring sudden changes, declines or increases in the amount of individual items in the financial statements.

Table 6. Horizontal analysis of the balance sheet of Company D for the period 20XX-4 and 20XX-

Assets				
Description of balance sheet position	20XX-4	20XX-3	Absolute difference	Relative difference
	t_{-1}	t	$t - t_{-1}$	t / t_{-1} (%)
Real estate, facility and equipment	110	86	(24)	78
Capital and liabilities				
Description of balance sheet position	20XX-4	20XX-3	Absolute difference	Relative difference
	t_{-1}	t	$t - t_{-1}$	t / t_{-1} (%)

Capital	308	308	0	100
Long-term loans	52	54	2	104
Obligations based on wages and salary benefits	200	214	14	107
Other short-term liabilities	20	20	0	100
Obligations for other taxes and other duties	2	2	0	100
Accrued costs and deferred revenues	16	16	0	100

(Source: processed by the authors.)

Table 7. Horizontal analysis of the balance sheet of Company D for the period $20XX_{-3}$ and $20XX_{-2}$

Assets				
Description of balance sheet position	$20XX_{-3}$	$20XX_{-2}$	Absolute difference	Relative difference
	t_{-1}	t	$t - t_{-1}$	t / t_{-1} (%)
Real estate, facility and equipment	86	0	(86)	n/a
Capital and liabilities				
Description of balance sheet position	$20XX_{-3}$	$20XX_{-2}$	Absolute difference	Relative difference
	t_{-1}	t	$t - t_{-1}$	t / t_{-1} (%)
Capital	308	228	(80)	74
Long-term loans	54	54	0	100
Obligations based on wages and salary benefits	214	216	2	100
Other short-term liabilities	20	20	0	100
Obligations for other taxes and other duties	2	2	0	100

Accrued costs and deferred revenues	16	16	0	100

(Source: processed by the authors.)

The tables show a horizontal analysis of key positions for the period $20XX_{-4}$ to $20XX_{-2}$. Since their values did not change in the period from $20XX_{-2}$ to 20XX, we will not present that period in this paper.

On the basis of tabular representations of the horizontal analysis of the financial statements of Company D, the temporary bankruptcy administrator detected balance positions for which there is a suspicion that accounting manipulations were carried out, namely: Real estate, facility and equipment, and Capital. Therefore, the temporary bankruptcy administrator reviewed the submitted bookkeeping documentation and asked to supplement it in order to determine whether there is a basis for refuting the legal actions.

The conclusion of the case study - Bankruptcy debtor D, was derived based on primary data from table 5. Balance sheet of Company D for the period $20XX_{-4}$ - 20XX, as well as by analysing the results obtained in table 6. Horizontal analysis of the balance sheet of Company D for the period $20XX_{-4}$ and $20XX_{-3}$ and table 7. Horizontal analysis of the balance sheet of Company D for the period $20XX_{-3}$ and $20XX_{-2}$. The same reads:

It is concluded that the balance positions where accounting manipulations were detected based on the data from table 6. Horizontal analysis of the balance sheet of Company D for the period $20XX_{-4}$ and $20XX_{-3}$ and table 7. Horizontal analysis of the balance sheet of Company D for the period $20XX_{-3}$ and $20XX_{-2}$: Real estate, facility and equipment and Capital.

The description of the actions taken is as follows: Company D had a building object and equipment (various machines) registered under the position "Real estate, facility and equipment". One month before submitting the proposal for the initiation of bankruptcy proceedings, the director of the Company made a decision to write-off these fixed assets. The decision states that the construction object should be write-off because it is owned by the parents of the company member, and the equipment has worn out due to non-use and commissioning. According to the decision, the amount of the residual value of these assets should be charged to the depreciation cost for the year $20XX_{-2}$. The mentioned decision was implemented retroactively through the financial statements, i.e. on $31.12.20XX_{-2}$.

By comparing the situation in the court register, land registers and business registers, it was determined that the Company made a recapitalization in $20XX_{-15}$ in terms of assets (real estate and equipment). On that occasion, a carpentry workshop was included in the basic capital, but after the capital increase in the court register, the members of the company did not transfer the ownership rights to the Company in the land registers.

Evidence of the committed actions are: financial statements (balance sheet) of Company D for the period 20XX-4 to 20XX, Decision on asset write-off, from March

20XX, and Decision on entry of changes in data on the subject of entry into the court register, from 20XX-15.

The basis for rebutting the legal actions is: The write-off of the assets of Company D without prior reduction of the basic capital and implementation of the procedure according to the Law on Business Companies of the Federation of Bosnia and Herzegovina, and the increase of the depreciation rate on fixed assets, and all this based on the decision of the director of the company, which was made only a few days before the filing of the proposal for bankruptcy, as well as the retroactive effect of the decision, has the characteristics of a disputed legal action according to Article 139 of the Law on Bankruptcy of the Federation of Bosnia and Herzegovina, which reads: "Legal actions taken before the opening of the bankruptcy procedure, which violate the equal settlement of creditors (damage to creditors)..."

Applying the aforementioned article of the Law to the specific case, it can be concluded that the action was taken (March 20XX) before the filing of the proposal for opening bankruptcy (April 20XX), and it disrupts the equitable settlement of creditors by reducing the bankruptcy estate. By such a decision, the company director knowingly and intentionally cancels the assets of Company D, and does so retroactively by increasing the depreciation rate.

The responsibility of the members of the Company can also be sought based on Article 316 of the Law on Business Companies of the Federation of Bosnia and Herzegovina, which reads: "For the amount of the unpaid part of the deposit, which is required to settle the bankruptcy creditors (...), the members of the company in bankruptcy are jointly and severally liable (...)".

4. Concluding considerations

The application of forensic accounting to the balance sheet position of the capital enables precise detection of irregularities and attempts to reduce the bankruptcy estate, which significantly contributes to the efficiency and fairness of the bankruptcy procedure. Forensic accounting plays a key role in increasing the efficiency of bankruptcy proceedings, especially in the context of precise determination of the balance sheet position of capital and the detection of manipulative actions that precede bankruptcy. By applying forensic methods, it is possible to analyse in detail the financial situation of the bankrupt debtor, to detect irregularities and potential fraud, which directly protects the interests of creditors and ensures greater transparency of the procedure.

The results of the analysis showed that forensic accounting contributes to the timely identification of risks and ensures the reliability of balance sheet data, which enables a fairer distribution of assets and increases the confidence of all participants in the procedure. The paper presents a concrete way of applying forensic techniques to the

capital position, with the aim of maximizing benefits for creditors of the bankrupt debtor.

In addition to establishing the factual situation, forensic accounting proves to be an efficient instrument for investigating and proving fraud aimed at reducing the bankruptcy estate, which violates the principle of equal settlement of creditors. The essence of the approach is the return of property to the bankruptcy estate and initiation of appropriate legal actions against the responsible persons, in accordance with the Bankruptcy Law of Federation of Bosnia and Herzegovina.

In a broader sense, the conclusion is that the temporary bankruptcy trustee should not rely exclusively on the submitted documentation and financial statements. Since his report is the basis for the decision to open bankruptcy proceedings, it is extremely important that he analytically identifies suspicious areas, identifies possible elements of fraud and assesses whether the actions are subject to rebuttal according to the legislative framework.

Only this approach enables the bankruptcy procedure to fulfil its purpose - maximization of the value of the bankruptcy estate, equal settlement of creditors and preservation of the order of claims. Therefore, it is recommended that forensic accounting be systematically integrated into all stages of bankruptcy proceedings, in order to ensure greater efficiency, fairness and legality of the process.

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The Necessity, Approaches and Mechanisms for Amending the Constitution in Light of the Judgments of the European Court of Human Rights

Jasmina Bešlagić and Adna Ziric

Faculty of Law, University of Bihać, Bihać, Bosna and Herzegovina

E-mail: jasmina.beslagic@unbi.ba

Abstract. The Constitution of Bosnia and Herzegovina, established as Annex IV of the Dayton Peace Agreement, created a complex institutional framework aimed at maintaining peace and stability in the country. However, this constitutional model, based on the principle of the constituent peoples, often presents challenges in the functioning of state institutions, decision-making processes, and ensuring equality for all citizens. This paper explores the specific mechanisms of governance in Bosnia and Herzegovina, including the distribution of competences among the state level, entities, cantons, and the Brčko District, while analyzing how the existing constitutional structure impacts institutional efficiency and the country's democratic development. Special focus is placed on the relationship between the collective rights of the constituent peoples and the individual rights of all citizens, considering the challenges this model poses in the context of European democratic standards. The paper examines the legal and political aspects of potential constitutional reforms, including possible models for aligning Bosnia and Herzegovina's institutional framework with international and European legal standards. Key issues analyzed include the legal nature of the Constitution of Bosnia and Herzegovina, the role of the Constitutional Court in interpreting its provisions, as well as the limitations and opportunities for institutional reform. The study offers a comparative analysis of other complex political systems to identify potential solutions for improving the functionality of Bosnia and Herzegovina's governance model. Special attention is given to reform proposals aimed at enhancing institutional efficiency, ensuring a balance between ethnic and civic principles, and strengthening the rule of law and democratic processes in Bosnia and Herzegovina.

Keywords: constitutional law, governance, Bosnia and Herzegovina, distribution of competences, constitutional reforms, collective and individual rights, institutional framework, democratic standards

1. Introduction

The constitutional framework of Bosnia and Herzegovina[1] reflects a compromise between international norms, the specific demands of ethnic communities, and the

[1] **The General Framework Agreement for Peace in Bosnia and Herzegovina**, initialed on November 21, 1995 in Dayton (USA) and signed on December 14, 1995 in Paris, established the fundamental principles of the constitutional and political order of Bosnia and Herzegovina. An integral part of this Agreement, as its Annex 4, is the **Constitution of Bosnia and Herzegovina**, which, in addition to the Preamble, consists of twelve articles.

politics of a post-conflict society. However, given its provisional and crisis-based nature, the Constitution has over time become a major obstacle to the realization of fundamental human rights and the functioning of a democratic system. This is confirmed by the judgments of the European Court of Human Rights which have identified multiple forms of discrimination and systemic incompatibility with the European Convention on Human Rights. The fundamental challenge facing Bosnia and Herzegovina today is to find an institutional and legal solution that reconciles two key and often conflicting principles: the principle of the constituent peoples, which safeguards the collective rights of Bosniaks, Croats, and Serbs, and the principle of individual equality, which affirms the universal right of every citizen to equal political participation. The European Court of Human Rights rulings—especially in the cases of *Sejdić and Finci v. Bosnia and Herzegovina*[2], *Zornić v. Bosnia and Herzegovina*[3], *Pilav v. Bosnia and Herzegovina*[4], and *Šlaku v. Bosnia and Herzegovina*[5]—clearly indicate the need for comprehensive constitutional reform to ensure a balance between collective and individual rights and eliminate all forms of discrimination in the electoral and political system.This tension between collective representation and universal civic rights is not only normative but also deeply embedded in the socio-political fabric of BiH, marked by identity-based divisions, historical trauma, and distrust. While the Dayton formula of power-sharing was effective in stabilizing the post-conflict society, it now generates dysfunctions that significantly hinder democratic development, economic modernization, and the integration process. Consequently, Bosnia and Herzegovina faces the necessity of redefining its constitutional order to ensure equal political participation for all citizens, including those who do not identify as members of a constituent people. In the context of European Union accession, constitutional reform is no longer merely an internal political matter but a condition sine qua non for achieving EU membership. Therefore, it is essential to initiate an inclusive and transparent dialogue among all relevant stakeholders—including government institutions, opposition, civil society, academia, and international partners—to reach broad social consensus on the direction of constitutional change. This dialogue must aim to achieve a new constitutional model that integrates the highest standards of human rights, ensures institutional functionality, and protects identity.

2. The Constitution As A Doctrine Of Statehood

The legal nature of the Constitution of Bosnia and Herzegovina constitutes a fundamental framework for its understanding as the primary document that defines the legal, political, and institutional identity of the state. The Constitution of BiH is not merely a domestic act with constitutional authority but also an international legal instrument. This fusion of international and domestic law renders the Constitution a

[2]**Applications Nos. 27996/06 and 34836/06, available at:** https://www.mhrr.gov.ba/ured_zastupnika/novosti/default.aspx?id=1008&langTag=bs-BA
[3]**Application No. 3681/06, available at:** http://www.sluzbenilist.ba/page/akt/LmZmjnprVGE
[4]**Application No. 41939/07. For more information, please refer to:** https://www.mhrr.gov.ba/PDF/UredPDF/default.aspx?id=6680&langTag=bs-BA
[5]**Application No. 56666/12. Further information available at:** http://www.sluzbenilist.ba/page/akt/LdD8vgztz5k76kjn45bSQ0jQ

unique type of constitutional document, reflecting a complex legal nature shaped by specific historical and political circumstances. The Constitutional Court of Bosnia and Herzegovina consistently emphasizes that the Constitution is the result of international negotiations, and as such, it possesses distinct legal personality and binding force that transcends the classical domestic constitutional act. This legal nature has direct implications for the process of its amendment, application, and interpretation: future changes cannot be considered solely as internal political decisions but must comply with the fundamental principles of the Dayton Agreement, international law, and the legal obligations of Bosnia and Herzegovina. Furthermore, the fact that the Constitution was adopted as an imposed framework of international consensus, lacking direct democratic legitimacy from the population, further complicates its status and legitimacy in the eyes of the domestic public and academic community.

The Constitution of Bosnia and Herzegovina was adopted in the English language and has never been formally translated and published in the official languages of the country, which represents another peculiarity illustrating its international character. Its significance stems not only from its formal legal status but also from the function it serves in defining the state itself: it establishes the basic principles and rules of government organization and the relations between different levels of authority and ethnic communities. However, this constitutional construction simultaneously represents both a product of significant compromises and political constraints that arose under the pressure of the international community and internal actors. The Dayton Constitution emerged as a result of international consensus among major powers, which entailed the sacrifice of the original constitutional order of the Republic of Bosnia and Herzegovina, established by referendum in 1992. The new constitution introduces a complex, often dysfunctional, and regressive system that has, in practice, revealed substantial weaknesses and challenges to long-term political stability and social integration. The constitutional order of BiH, created under international pressure, is not a classical constitutional model but rather a hybrid balancing federal and confederal elements, with clear institutionalization of ethnic divisions and the principle of collective rights of peoples. This approach institutionalizes ethnic representation as the basis for political action, thereby marginalizing civic rights and creating obstacles to the development of an inclusive, democratic society. Bosnia and Herzegovina is defined in the Constitution as a democratic state functioning in accordance with laws and the principles of human rights, freedoms, and equality. The preamble of the Constitution calls for respect for fundamental international standards—including the United Nations Charter, the Universal Declaration of Human Rights, and international treaties protecting the rights of national, ethnic, and religious minorities. However, practice and institutional structures frequently conflict with these ideals, reflecting deep tensions and dilemmas arising from the Dayton compromise. The political system of Bosnia and Herzegovina, as emphasized in scholarly literature, cannot be classified under a single classical model of state organization. It represents a unique form in which ethnic categories are central to political action, leading to divisions and complex tensions among the three constituent peoples. This ethnic basis of the political system often overshadows the potential for the development of political life grounded in civic principles and universal democratic values. Consequently, the

Constitution, although a key legal document, remains simultaneously a symbol of complexity as well as an obstacle to building a functional, democratic, and stable state.

3. The Obligation Of Bosnia And Herzegovina Towards The European Court Of Human Rights

Bosnia and Herzegovina, as a member of the Council of Europe[6], has reaffirmed its commitment to respecting human rights, democracy, and the rule of law — the fundamental principles upon which this European organization is founded. Simultaneously, by ratifying the European Convention on Human Rights and Fundamental Freedoms, Bosnia and Herzegovina undertook the obligation to ensure the full implementation and respect of the Convention's provisions within its legal system. This obligation is explicitly embedded in the Constitution of Bosnia and Herzegovina[7], which, in Article II, clearly stipulates that the rights and freedoms guaranteed by the European Convention constitute an integral part of the domestic legal order and may be directly applied by the courts of Bosnia and Herzegovina. Thus, Bosnia and Herzegovina has accepted the jurisdiction of the European Court of Human Rights as the ultimate guarantor of human rights protection, operating as the key mechanism safeguarding human rights in Europe. The Court ensures the enforcement of the Convention, which guarantees rights such as the right to life, prohibition of torture, freedom of expression, right to a fair trial, and prohibition of discrimination. Citizens of Bosnia and Herzegovina, as well as other interested parties, have the right to appeal to the Court if they fail to realize their rights through domestic judicial institutions. Moreover, it is emphasized that the rights under the European Convention must be effective and genuinely realizable, rather than merely declarative. Cases against Bosnia and Herzegovina reveal profound systemic deficiencies, particularly in the area of ethnic discrimination, as clearly demonstrated by the "Sejdić and Finci v. BiH" judgment. The current constitutional and legal framework of Bosnia and Herzegovina does not permit equal political participation for members of national minorities. In addition, in accordance with the principle of subsidiarity, Bosnia and Herzegovina is obligated to ensure the implementation and respect of the European Convention through its domestic legal mechanisms, while the European Court of Human Rights serves as a supervisory body and final instance of protection. Article 13 of the Convention provides for the right to an effective remedy at the national level, and Article 1 requires that the rights and freedoms guaranteed by the Convention be secured to everyone within the jurisdiction of the state. Consistent enforcement of the judgments of the European Court and harmonization of domestic legislation with the established standards are essential steps toward strengthening the rule of law, democracy, and citizens' trust in the legal system of Bosnia and Herzegovina. Therefore, fulfilling its obligations towards the European Court of Human Rights represents a

[6] By assuming the obligations arising from its membership, Bosnia and Herzegovina became the 44th member state of the Council of Europe on April 24, 2002. Through the adoption of over 90 conventions and accompanying protocols, BiH has been recognized as a cooperative member of the Council of Europe, sharing and promoting the values of this international organization.

[7] **For further information, see:** https://www.ustavnisud.ba/public/down/USTAV_BOSNE_I_HERCEGOVINE_bos.pdf

crucial element in the country's further development and integration into European legal and political frameworks.

4. The Need And Procedure For Amending The Constitution Of Bosnia And Herzegovina

The process of amending the Constitution of Bosnia and Herzegovina has represented one of the most important yet complex challenges for the country's political and legal system since its inception. As the fundamental legal act, the Constitution of BiH today faces numerous criticisms due to its complex structure, ethnically determined provisions, and misalignment with contemporary international human rights standards. A central reason for the need to amend the Constitution lies in the systemic discrimination against certain population groups, repeatedly confirmed by rulings of the European Court of Human Rights (ECtHR). The Court's jurisprudence clearly shows that the existing constitutional and electoral framework excludes members of national minorities and citizens who do not identify with the constituent peoples from the right to run for the Presidency of BiH and the House of Peoples of the Parliamentary Assembly of BiH. These judgments constitute international obligations of BiH which, according to the Constitution, are directly applicable and take precedence over domestic legislation. For a long time, electoral law reform has been at the forefront of these reforms as a key instrument for establishing a fair political system. In this context, particular significance is attached to the April package of constitutional amendments from 2006. This package, developed under pressure from the American and European administrations, encompassed a range of changes aimed at establishing a more efficient system of state authority, abolishing discriminatory provisions, and redefining competencies between the state and entities. It envisaged an expansion of exclusive competencies of Bosnia and Herzegovina, including areas of defense and security, as well as the establishment of state institutions such as the Court and the Prosecutor's Office of BiH. The package also defined shared competencies between the state and entities in areas like the tax system, judiciary, elections, agriculture, science, and ecology. One of the key goals was the elimination of discriminatory constitutional provisions that restricted the right to candidacy for the Presidency of BiH and the House of Peoples on the basis of ethnic affiliation and residence. Unfortunately, this package was not adopted in the Parliament of BiH as it failed to secure the required two-thirds majority. In addition to this, alternative solutions for the election of members of the Presidency of BiH have been proposed, primarily focusing on amendments to the Electoral Law to increase legitimacy and electoral fairness. However, none of these solutions addressed the fundamental issue of discrimination against members of national minorities. The amendments imposed by the High Representative Christian Schmidt in 2022, while improving technical aspects of the electoral process—such as campaign finance transparency, prevention of abuses, and regulation of candidacies—did not address the systemic discrimination embedded in the Constitution of BiH itself. This leaves the country in a legal vacuum and non-compliance with international human rights standards, adversely affecting the process of European integration. The

Constitution of Bosnia and Herzegovina, particularly through Article II, formally guarantees the protection of the highest internationally recognized human rights and fundamental freedoms, as well as the direct application of the European Convention on Human Rights and Fundamental Freedoms and its protocols. This article explicitly states that the rights and freedoms enshrined in the Convention apply directly and have precedence over all other laws. Furthermore, the Constitution explicitly prohibits amendments that could diminish or remove these rights and freedoms, ensuring that fundamental human rights remain unchanged regardless of political shifts. However, practice shows that this constitutional protection is insufficient to eliminate institutional obstacles and ethnic privileges embedded in the country's political system. The political structure, based on the concept of constituent peoples, often results in different rights and opportunities for citizens who do not identify with any of the constituent peoples or who live in different entities, creating space for indirect discrimination and inequalities. Constitutional reforms should include additional legal guarantees for the protection of human rights and freedoms, aligning the domestic legal system with European standards and ECtHR rulings. This would reduce discriminatory practices, ensure legal security for citizens, and further strengthen democratic values within Bosnia and Herzegovina. It is also necessary to redefine competencies between the state and entities with the aim of establishing clearer and more efficient institutions that guarantee more effective management of key functions such as defense, security, and judiciary. Such changes would strengthen state sovereignty and reduce administrative fragmentation, which currently hinders the functioning of the state. Equally important is improving the functionality of the Parliamentary Assembly of BiH by amending decision-making procedures. This would prevent frequent blockages caused by ethnic divisions and enable more efficient adoption of laws and constitutional amendments, which is crucial for the country's long-term stability and development. The process of amending the Constitution of Bosnia and Herzegovina requires not only political will and broad consensus among representatives of the three constituent peoples but also the inclusion of all citizens, respecting human rights and European democratic standards. According to the Constitution, amendments are adopted by a decision of the Parliamentary Assembly of BiH with a two-thirds majority in the House of Representatives and the consent of the House of Peoples, which poses an additional obstacle given deep political divisions and interests. Despite the complexity, the necessity of amendments is evident—without them, Bosnia and Herzegovina will not be able to achieve full political stability, establish a functional and inclusive system, or accelerate its European path.

5. Conclusion

Amending the highest legal act of a country, such as the Constitution of Bosnia and Herzegovina, represents a multidimensional and highly complex process that goes beyond legal formalism, as it deeply touches upon the political, social, and historical realities of the country. In the case of Bosnia and Herzegovina, this process carries additional weight due to the specific constitutional structure established by the Dayton

Peace Agreement, designed as a framework to maintain a fragile balance between different peoples and entities but which simultaneously imposes numerous challenges on the functionality and legal security of the state. Constitutional changes should not be perceived merely as a technical act of adapting the existing legal system to new circumstances, but as a process requiring broad political consensus and careful balancing of interests among all relevant actors. The challenge is to reconcile the protection of collective identities with the principles of universal equality and human rights to avoid further deepening divisions and marginalization. Only through such balance is it possible to build a political framework that is acceptable and sustainable in the long term. In this context, the process of amending the Constitution should be aimed at achieving a stable and functional state system that simultaneously respects the rights of all citizens and guarantees effective governance. This implies the necessity of clearly defining competencies and responsibilities within the multi-layered structure of authority, as well as improving mechanisms of political participation and protection of human rights without compromising sovereignty and internal cohesion. Ultimately, the success of this process depends on the political will and readiness of all involved parties for compromise and dialogue, since without a genuine shared vision and mutual trust, any constitutional reform may deepen existing divisions and hinder the path to stability and prosperity. Therefore, the future of Bosnia and Herzegovina largely depends on its ability to transform the current constitutional framework from a temporary, post-conflict arrangement into a long-term, inclusive, and democratic structure that meets the demands of modern society and the rights of all its citizens.

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Robots and actions of robots in the Civil Law regime in Bosnia and Herzegovina

Belma Bajrić[1], Hajro Kofrc[2], Refik Šahinović[3] and Benjamin Muhamedbegović[4]

[1] Faculty of Law, University of Bihac, Bihać, Bosnia and Herzegovina
[2] Faculty of Law, University of Tuzla, Tuzla, Bosnia and Herzegovina
[3] Biotechnical Faculty, University of Bihac, Bihać, Bosnia and Herzegovina
[4] Faculty of Technology, University of Tuzla, Tuzla, Bosnia and Herzegovina

E-mail: belmabajric5@gmail.com

Abstract. Without the actions of robots, certain research fields of science and various types of industry would be unimaginable in the world today, which is also contributed to the rapid development of artificial intelligence, as well as the ever-present automation of work process. What kind of legal regime has been established in Bosnia and Herzegovina over the actions of robots, how they are treated in the field of civil law from the aspect of real law and obligation law with an emphasis on the sphere of civil law delicts, that will be the question to which the authors will provide an adequate legislative and theoretical section by analyzing positive legal regulations.

1. Introduction

The actions of robots in industry, agriculture, medicine and other branches are regular tools in the standard procedures of production, treatment, etc. in the world today. Bosnia and Herzegovina[8] applies the advantages that robotics brings with it in all spheres of production to an almost insignificant extent and is therefore absent in modern trends, which is why it weakens its positioning on the market and reduces the competitiveness of its production with other countries that continuously invest a lot in the processes of improving the production and the quality of the obtained products by applying new advanced technologies, including robots. Robots have become a reality in the economic sector, they are used not only in industry, agriculture, medicine and in tourism (gastronomy, hotel industry, etc.), but the further potential of their application in other areas, and even in education, can also be seen.

[8] Hereinafter: BiH

From the civil law aspect, robots and robot actions are clearly defined through legal provisions. The purpose of the paper is to present the legal definition and understanding of robots and robot actions from the point of view of real law and obligation law as an inevitability that will increasingly permeate into the real sector.

2. Robots and actions of robots from the aspect of Civil Law in Bosnia and Herzegovina

Throughout history, man's eternal preoccupation has been how to make it easier for himself to perform difficult and tedious tasks. With the development of science, but also with the greater accumulation of capital by individuals and groups, it was realized that this huge problem could be solved by applying technology.[9] The name "robot" was first encountered in the 20th century.[10] Today, robotics occupies a significant place in the development of science, but also in specific branches of the economy. Many more advantages have been realized with the introduction of advanced technologies, especially robots, in almost all spheres of the economy, but there are also disadvantages, such as the expensive process of purchasing robots, which consequently leads to the impossibility of introducing robots into production and providing services, then the impossibility of purchasing robots through a leasing contract due to the enormously high leasing fee and the limitation of the robot owner by transferring the right of use to third parties, the dependence of the lessee on the lessor, etc. All these are important moments that accompany robotics in the economic world.

In Bosnia and Herzegovina, robots and the actions of robots from the civil law aspect can be viewed from the point of view of real law and obligation law and their legal determination can be determined.

From the point of view of civil law, the robot represents an object of civil law relations, that is, a thing in the ownership regime of its owner.[11] The robot as an object of civil law relations is studied within the framework of real law. And in accordance with that teaching, a robot can be said to be an independent, mobile[12], thing in circulation[13], replaceable[14], non-consumable[15], indivisible[16], composed thing with independent parts, evaluable[17], and in certain cases it can be considered belonging or pertinence.

[9] The first ideas and implementations of mechanical automata are quite old. They have been resting since ancient times, when in 880 B.C. Homer described movable tripods in the Iliad, and then Aristotle in 350 BC. "fantasized" about mechanisms whose work would be based on "obedience and intuition", and already in 1350 a mechanical rooster was mounted on the top of the Cathedral in Strasbourg, France. In 1801, the Frenchman Joseph-Marie Jacquard designed and demonstrated an automatic textile loom controlled by punched cards. Seward Babbitt then designed a motorized crane and grippers for removing steel ingots from blast furnaces. More widely: Doleček, Vlatko – Karabegović, Isak, Robotics, Technical Faculty, Bihać, 2002, p. 5-7.

[10] The term was first coined by Czech writer Karel Čapek in 1921 in his play "R.U.R." (Rossum's Universal Robots), in which he described robots as beings similar to humans but without emotions. The term "robot" comes from the Czech word "robota", which means mercenary or serf. Loc. cit.

[11] According to Art. 5, paragraph 1 of the Law on Real Rights of the Federation of BiH (Official Gazette of the Federation of BiH, No.: 66/2013. and 32/2019. – decision of the Constitutional Court), things within the meaning of this law are material parts of nature, which may be in the possession of a natural or legal person, unless due to their natural properties or limitations based on a special law they are not suitable to be the object of ownership rights and other real rights.

[12] Lat.: *res mobiles*

[13] Lat.: *res in commercio*

[14] Lat.: *res fungibiles*

[15] Lat.: *res non consumptibiles*

[16] Lat.: *res indivisibiles*

[17] Lat.: *res aestimabiles*

When the robot is viewed through the criterion of natural properties, it is necessary to provide more detailed explanations. Based on the above criteria, the robot represents an independent movable thing.[18] However, if the robot were to be viewed through the criterion of pertinence, then it could be considered real estate by purpose.[19] According to the criterion of pertinence, a thing that is movable by its natural physical properties is also considered real estate.[20] This is the case with a robot. Namely, pertinence represents an attachment to another thing, or rather, a movable thing that permanently serves the economic purposes of the immovable.[21] It is important to emphasize that an attachment or pertinence is considered a secondary or collateral movable thing (in this case, a robot) that is determined to permanently serve the economic purposes of a main thing (agricultural, industrial, craft or service activity), without becoming its integral part.[22] In accordance with the above, a robot is in a relationship of subordination (subordination) to the main thing, because it follows the legal fate of the main thing.[23]

The actions of a robot are also objects of civil law relations, but as such they must be viewed through the prism of acts, or rather, through the prism of obligations. Namely, the following question arises: "Are the actions of a robot acts, given that a robot is a thing?" An obligation relationship[24] consists of its content and subjects, along with the legally relevant fact that led to its establishment. The content of an obligation relationship includes two elements: the creditor's right to claim and the debtor's obligation. The debtor's obligation is also referred to as the subject of the obligation relationship, i.e. the subject of the obligation relationship is the conduct to which the debtor has committed himself, which also represents the right to demand/claim to which the creditor is authorized.[25] The answer to the question posed must be sought in the definition of the act itself, which implies any positive or negative human action that the debtor is obliged to perform to the creditor on the basis of the obligation

[18] In accordance with Art. 6, paragraph 3 of the Law on Real Rights of the Federation of BiH, movables are things that can be moved from one place to another without changing their substance (essence). Prof. Vedriš and Prof. Klarić consider movables to be those things that can change their position in space without destroying their essence (substance), that is, without changing their previous structure. See: Vedriš, Martin – Klarić, Petar, Civil Law, National newspaper , Zagreb, 2002, p. 74.

[19] The Law on Real Rights of the Federation of Bosnia and Herzegovina considers real estate to be particles of land, together with everything that is permanently connected to the land on the surface or below it, unless otherwise provided by law (Art. 6, paragraph 2).

[20] In Art. 6, paragraph 4 of the aforementioned Law, it is added that things that are movable by their nature are considered immovable in the legal sense if they belong to real estate or the law equates them with real estate.

[21] For example, real estate is considered to be machinery, livestock, seeds, fertilizer, fuel, etc. intended for agricultural production on an agricultural holding, as well as business buildings, machines and similar devices that permanently serve the purpose of a building intended for production or craft activities, because the owner of the real estate has determined that these movables permanently serve the economic purposes of that real estate. More: Vedriš, M. – Klarić, P. op. cit., pp. 75-76. The Real Rights Act regulates the ownership of things in Art. 11.

[22] Movables and real estate can have ownership.

[23] *Assessorium sequitur principale! Summa summarum*, an accessory is an independent, but secondary movable thing, accompanied by an element of permanence (it permanently serves certain purposes of the main thing), whereby its creation and survival are determined by the will of the owner of the main thing, who determines one of his other things to become an accessory of the first. Therefore, the owner of the main thing and the owner of the accessory are the same person, or rather, the Law on Real Rights clearly stipulates this under the condition that there are no rights of third parties on these things that are entered in the appropriate public register (Art. 11, paragraph 4). Thus, only that thing that is considered an accessory in normal circulation can be made an accessory. See: Vedriš, M. – Klarić, P. op. cit., pp. 82-83.

[24] Lat.: *obligatio, obligare* - vezati

[25] Obligatory behavior of the debtor is called action, and it can be in the form of dare (Latin: surrender), facere (Latin: action), non facere (Latin: inaction, failure) and pati (Latin: suffering). Read: Antić, Oliver, Law of Obligations, Law Faculty of the University of Belgrade, Belgrade, 2014, p. 50-70s; Babić, Ilija - Jotanović, Radenko, Civil Law - Introduction to Civil Law, Faculty of Law, University of Banja Luka, Banja Luka, 2018, p. 148-152. and Šarac, Mirela – Lučić, Zdravko, Roman Private Law, Faculty of Law, University of Sarajevo, Sarajevo, 2006, p. 165-167.

relationship. In order for an act or omission to be considered an act, the following legal characteristics must be cumulatively met:

- the act must be a human act,
- the act must have a property character and
- the act must be possible, permitted and determined or at least determinable.[26]

When it comes to the actions of a robot, the focus is on the first legal characteristic of the act, that it must be a human act. This stems from the definition of the obligational relationship as a type of civil law relationship, i.e. a legal relationship, which first and foremost originated as a social relationship into which natural and legal persons enter. An obligational relationship is a legal relationship into which subjects enter in connection with acts. The act must be a manifestation of human activity or omission, and actions that originate from an elemental force, from an animal or from an automaton are not acts. The actions of an automaton are considered the actions of its owner, or the owner, i.e. the actions of the person using the automaton[27].

Therefore, the answer to the question posed above is that the action of a robot does not constitute an act. An act is the result of the physical or intellectual work of a human in the case of positive obligations, or his omission of his own or the suffering of another's action in the case of passive obligations.

In the context of robot actions, it is essential to mention the damages caused by the actions of robots. The question of liability for the damage caused arises. Liability for a civil tort is borne by the person (the tortfeasor) who, through his/her unlawful action, caused harmful consequences to the property of another person (the injured party). If the action of a robot causes the damage, then an obligation relationship based on true objective liability will arise, a liability that is not based on fault and that originates from a specific type of thing or activity. Damage caused in connection with a dangerous thing or dangerous activity is considered to originate from that thing or activity, unless it is proven that they were not the cause of the damage.[28] The ZOO does not contain a numerus clausus, i.e. it did not provide a list of dangerous things and dangerous activities. Potentially, all things and activities can be dangerous due to increased risk, including the actions of robots. The owner of a dangerous thing is liable for damage, and the person who engages in it is liable for damage from a dangerous activity. The holder is considered the owner of the thing, as well as the legal entity that has the right of disposal, that is, to whom the thing is given for temporary use.[29] The owner is released from responsibility if he proves that the damage originates from some cause that was outside the property, and the effect of which could not have been foreseen, avoided or

[26] Art. 46-50. Law on Obligations of the Federation of Bosnia and Herzegovina (Official Gazette of the SFRY, No. 29/1978, 39/1985, 45/1989 - decision of the Supreme Court of Justice and 57/1989, Official Gazette of the RBiH, No. 2/1992, 13/1993 and 13/1994 and Official Gazette No. 29/2003 and FBiH 42/2011), hereinafter: ZOO.
[27] Vedriš, M. – Klarić, P., op. cit., p. 89.
[28] Art. 173 ZOO
[29] Art. 174 ZOO

removed. The owner of the thing is released from responsibility if he proves that the damage was caused, exclusively, by the actions of the injured party or a third party, which he could not foresee and whose consequences he could not avoid or remove. The owner is released from responsibility partially, if the injured party partially contributed to the occurrence of the damage. If a third party partially contributed to the damage, he is liable to the injured party jointly and severally with the owner of the thing, and he is obliged to pay compensation in proportion to the severity of his fault. The person used by the owner when using the item is not considered a third party.[30] Therefore, the legislator prescribed this type of responsibility based on objective responsibility for the damage caused, regardless of the fault of the damager as a special case.[31]

3. Conclusion

There is no single definition of a robot in the world, but it is left to national legislation to regulate its definition in their legislative acts. Therefore, there is a need to address the definition of a robot and the actions of a robot from a civil law aspect in Bosnia and Herzegovina. The topicality of the topic and diverse approaches (technical, economic) have led the authors to the realization that it is necessary to determine the legal nature of a robot and the actions of a robot from the aspect of objects of civil law relations.

A robot as an object of real law relations represents a thing on the basis of which people enter into the aforementioned relations. It is an independent thing, movable, a thing in circulation, interchangeable, non-consumable, indivisible, a composed thing with independent parts, estimable, and, subject to the fulfillment of certain legally prescribed conditions, also an affiliation or pertinence.

The actions of a robot do not constitute acts, because they do not meet the cumulative legal requirements for them to be treated as acts (the act must be a human act, must have a property character and the act must be possible, permitted and determined or at least determinable). The action of a robot is considered the action of its owner, i.e. the action of the person who controls the robot.

An interesting question is certainly the responsibility for damage caused by the actions of robots. ZOOs of the Federation of BiH/RS/Brčko District regulate responsibility for damage caused by the action of robots in the same way. Namely, there is no decisively prescribed liability for damage caused by the action of robots, but liability for such damage rests on liability for damage from dangerous things and

[30] Art. 177. ZOO

[31] Hence, in the Outline for the Code of Obligations and Contracts, prof. Konstantinović, starting with the regulation of the matter of objective responsibility for damage, defines only the concept of dangerous things with the marginal title "What things are considered dangerous" (Art. 136 of the Outline). According to this definition, the concept of dangerous things includes: movable or immovable things, whose position, or use, or characteristics or their very existence represent an increased danger to the environment (Art. 136, paragraph 1, Sketches). Based on this definition, the concept of dangerous activity proves to be unnecessary, because dangerous activity is nothing more than the use, that is, the way of using and functioning dangerous things. The editors of ZOO seem to have wanted to distinguish between dangerous things and dangerous activities, which is why they put the title of a special section. It is the department of the 5th ZOO. In court practice, a whole series of dangerous things and activities are mentioned (nuclear energy reactors, steam and gas-powered machines, electric machines, space objects...) Cited according to: Antić, O., op. cit., p. 492-499. and Blagojević Borislav – Krulj, Vrleta, Commentary on the Law on Obligations, Contemporary Administration, Belgrade, 1983, p. 480-483. See also: Klarić, Petar, Compensation law, Narodne novine, Zagreb, 1996, p. 191.

dangerous activities. Whereby all ages and activities can be dangerous due to the increased risk, even the actions of robots. The owner is responsible for damage caused by a dangerous thing, and the person engaged in it is responsible for damage caused by a dangerous activity. The holder is considered the owner of the thing, as well as the legal entity that has the right of disposal, that is, to whom the thing is given for temporary use. There are also cases of exemption from liability for damage caused by dangerous things or dangerous activities, with the fact that it is very important to emphasize that this form of liability for damage is based on objective responsibility, regardless of the fault of the damager.

The theme is quite inspiring and leaves room for some future upgrades.

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Advantages and Challenges in the Implementation of Entrepreneurship Education in Higher Education Institutions in Bosnia and Herzegovina from the Perspective of Teaching Staff

Elvira Ćatić-Kajtazović, Selma Šumar and Mirela Kljajic-Dervic

University of Bihac, Faculty of Economics, Bosnia and Herzegovina

E-mail: elvira.catick@gmail.com

Abstract. The paper presents the main findings of a study conducted on a sample of professors and associates from four public universities in Bosnia and Herzegovina (BiH). The research focuses on the types and objectives of entrepreneurship education implemented at public higher education institutions in BiH, as well as on respondents' perceptions of the challenges related to the implementation of entrepreneurship education at public universities. The results indicate that the main barriers to implementing entrepreneurship education, as perceived by the professors and associates, include a lack of financial resources, low awareness of the importance of entrepreneurship education, institutional inertia of higher education institutions (HEIs), student passivity, insufficient training, outdated curricula, and even resistance from other professors. Only 30.9% of respondents consider themselves competent and are involved in entrepreneurship education. Additionally, 12.9% feel competent but believe they lack the opportunity to implement entrepreneurship education. A significant 80% of respondents expressed interest in participating in some form of training on the topic of entrepreneurship education. The study highlights the need to improve both the understanding and implementation of entrepreneurship education within higher education institutions in Bosnia and Herzegovina. The research also identified the importance of further training for higher education teaching staff to effectively deliver entrepreneurship education, as well as the need for more effective communication of strategic documents related to entrepreneurship education in BiH.

1. Introduction

Since "entrepreneurship education is often regarded as an important development and economic mechanism" [1], it is argued that entrepreneurship education (EE) in Bosnia and Herzegovina (BiH) should be given strategic importance. However, after the "Strategy for Entrepreneurial Learning in the Education Systems in Bosnia and Herzegovina for the period 2012–2015, with an Implementation Action Plan" (in the

following text: Strategy), the next strategic document was adopted only in 2020, when the Council of Ministers of BiH, upon the proposal of the Ministry of Civil Affairs, adopted the "Priorities for the Integration of Entrepreneurial Learning and Key Entrepreneurial Competence into the Education Systems in Bosnia and Herzegovina (2021–2030)" [2]. In October 2016, the Council of Ministers adopted conclusions on the evaluation of the Strategy's implementation, noting progress in integrating entrepreneurship into the education systems in BiH, but also that the objectives and activities had not yet been fully achieved [3]. Despite the Strategy, the Priorities, and several implemented projects (mostly funded by the EU and/or individual embassies in BiH and/or ministries) focused on entrepreneurship, there is no known systematic review of the effects of strategic documents, implemented projects, or their outcomes. Thus, a lack of a systematic approach in the implementation and development of entrepreneurship education in BiH became evident at the outset of this study.

Given the identified research gap, a study was conducted on a sample of teaching staff from higher education institutions in BiH. Among other aims, the research sought to examine how familiar academic staff at public universities in BiH are with the "Strategy for Entrepreneurial Learning in the Education Systems in Bosnia and Herzegovina for the period 2012–2015, with an Implementation Action Plan," as well as to identify the main advantages and challenges in implementing entrepreneurship education.

As noted by [1], although the importance of entrepreneurship education for economic and social development is widely recognized, entrepreneurship and entrepreneurship education still face challenges in being accepted within the academic community. To overcome these challenges, [4] emphasize that "it is necessary to activate the dynamic role of the university in promoting entrepreneurship among university students."

2. Literature Review

As stated by [5], "entrepreneurship education represents a mix of entrepreneurial learning, skill development, and most importantly, a change in mindset," while [6] argues that entrepreneurship education "includes a range of educational activities and training, both within and outside the formal education system, aimed at developing the intention to engage in entrepreneurial behavior or elements that influence such intentions, such as entrepreneurial knowledge, the desirability of entrepreneurial activity, or its feasibility." This definition particularly highlights the role of non-formal education. Therefore, participants in the study were also asked specific questions regarding extracurricular activities. In this context, [7] emphasize that the main goal of entrepreneurship education is to develop an entrepreneurial spirit and culture among

students, thereby reinforcing the importance of entrepreneurial awareness and activity in various educational settings.

As stated in the Priorities [3], the Strategy has contributed significantly to the development of entrepreneurial learning and the integration of entrepreneurial competence in BiH, while previously defined strategic priorities remain:

1. Establishing partnerships for entrepreneurial learning;
2. Raising awareness of entrepreneurial learning at all levels;
3. Promoting entrepreneurial learning in primary and secondary education (formal education – key competence-based approach);
4. Promoting entrepreneurial learning in higher education;
5. Promoting entrepreneurial learning in adult and non-formal education;
6. Implementing and monitoring the strategy.

The Priorities further state that significant support for the implementation of the Strategy was provided by the project "Entrepreneurial Learning in the Education Systems in BiH" – Phase II (funded by the EU), which led to the introduction of entrepreneurial competence in 42 schools, and training of 483 teachers from 86 primary and secondary schools on how to integrate entrepreneurial competence into teaching and learning [3].

As previously mentioned, despite the existence of strategic documents and individual projects, BiH lacks a systematic review of their implementation and their effects on the development of entrepreneurship education. While gathering data on the reporting and results of the Strategy's implementation, we found a performance audit report titled Strategic Management at the State Level of Bosnia and Herzegovina, No. 05-16-1-1100/18 (...). "The goal of the audit was to determine whether the Council of Ministers and BiH institutions are taking all necessary measures to ensure an effective system for planning, developing, adopting, and implementing strategies, as well as for reporting on implementation results and impacts" [8]. This performance audit included the Strategy for Entrepreneurial Learning in the Education Systems of BiH for the 2012–2015 period. The audit report states that although the Strategy had foreseen annual monitoring of its implementation, due to various reasons, it was decided that an evaluation report would only be prepared at the end of the Strategy's validity. Even in that final evaluation, information on the implementation of specific activities was missing [8]. Furthermore, according to [8], in the accompanying Information Report on the implementation of the Strategy, the Council of Ministers concluded: "The Council of Ministers notes that significant progress has been made in implementing the Strategy for Entrepreneurial Learning in the Education Systems in Bosnia and Herzegovina for the period 2012–2015, but that the strategic priorities and activities from the Action Plan have not yet been fully achieved. The Council of Ministers calls on educational and other competent authorities—key partners in the education sector—to intensify the implementation of ongoing activities in the field of entrepreneurial learning."

When it comes to the Priorities for the integration of entrepreneurial learning and key entrepreneurial competence into the education systems in Bosnia and Herzegovina (2021–2030), there is reasonable expectation of more regular reporting and better monitoring of implementation. However, the practice of some responsible institutions failing to submit the required responses appears to be continuing. This conclusion is based on an official statement from the 61st session of the Council of Ministers of Bosnia and Herzegovina, held on October 17, 2024 [9]. It shows that the Council adopted the Information Report on the implementation of the Priorities, which was compiled based on responses from institutions responsible for implementation. However, the Ministry of Education and Culture of Republika Srpska, along with three cantonal ministries of education, failed to submit the requested responses.

Given the identified lack of evaluation studies on the effects of the Strategy for Entrepreneurial Learning (2012–2015), a study was conducted with a sample of academic staff from higher education institutions in BiH. Taking into account the timeframe of the Strategy for Entrepreneurial Learning (2012–2015), the research was conducted in 2017 on a sample of professors and associates from public universities in Bosnia and Herzegovina. One of the aims was to assess the extent to which professors and associates at public universities in BiH are familiar with the Strategy and its accompanying Action Plan. The study also aimed to identify the key advantages and barriers in implementing entrepreneurship education.

3. Results

According to [10], authors [11] and [12] recognize education 'for', 'about', 'through' and 'in' entrepreneurship. To ensure more accurate responses and avoid potential misunderstandings, the questionnaire also included additional explanations taken from [5]. A total of 55 professors and associates from four public universities participated in the study, of whom 45 were employed at faculties of economics.

Table 4 Training and type of EE

Questions	**Frequency**	**%**	**Missing**	**Total**
Have you attended any form of training on entrepreneurship education?				55 (100%)
Yes	30	54.5		
No	25	45.5		
Would you like to participate in some form of training on entrepreneurship education?			1 (1.8%)	54 (98.2%)
Yes	44	80.0		
No	10	18.2		

Questions	Frequency	%	Missing	Total
What type of EE should be implemented at your HEI?			1 (1.8%)	54 (98.2%)
'About' entrepreneurship	4	7.3		
'For' entrepreneurship	9	16.4		
'Through' entrepreneurship	14	25.5		
'In' entrepreneurship	1	1.8		
All of the above	26	47.3		

Regarding competencies for delivering entrepreneurship education, 30.9% of respondents consider themselves competent and are actively involved in teaching entrepreneurship, while 12.9% feel competent but do not have the opportunity to implement it. More than half of the respondents do not consider themselves competent to deliver entrepreneurship education. Specifically, 43.6% do not feel competent but would like to become competent, whereas 10.9% do not consider themselves competent and are not interested in entrepreneurship education.

Only 20% of respondents are familiar with the Strategy for Entrepreneurial Learning, 43.6% have heard of it but are unfamiliar with its content, and 36.4% have not even heard of its existence. The majority (81.8%) believe their superiors support new ideas, and 85.5% believe their superiors recognize the importance of entrepreneurship topics in teaching.

More than half of the respondents (51.11%) devote little or no time to extracurricular activities, on average up to 2 hours per week. Among the 30 respondents who described their activities, the most commonly mentioned were project work, student competition preparation, and skill development.

When describing the advantages of implementing entrepreneurship education at their higher education institution, respondents most frequently highlighted the following:

- encouraging students to start their own businesses,
- equipping students with practical skills, and
- fostering entrepreneurial awareness.
- creating a successful labour market orientation based on competencies
- raising awareness among students about the importance of strengthening entrepreneurship

Out of 40 collected responses, some examples include: "Acquiring knowledge and competencies and developing skills that enable students to start their own businesses/self-employment, while also empowering them to foster entrepreneurial spirit, innovation, and creativity—traits highly valued by employers today and prerequisites for intrapreneurship."

The main barriers to the implementation of entrepreneurship education, according to professors and associates, include a lack of financial resources, low awareness of the importance of entrepreneurship education, the inertia of higher education institutions

(HEIs), student passivity, insufficient training, outdated curricula, or even the attitudes of other professors.

Since most respondents are not directly involved in the management of their institutions, their ability to influence strategic decisions regarding entrepreneurship education may be limited, which could hinder or delay its development in higher education institutions. However, the majority of respondents (81.8%) believe their superiors support new ideas and proposals, creating a favourable environment for enhancing the implementation of entrepreneurship education.

From the 32 responses related to key barriers to implementing entrepreneurship education, the following were highlighted:

1. Professors and associates being narrowly focused on specific academic fields, resulting in a lack of understanding of the importance of entrepreneurship education.
2. Centralization of the university.
3. Administrative barriers (the university is a slow and rigid institution in terms of adopting changes), legal and statutory barriers (curriculum and syllabus changes are allowed only every four years and limited to 20%, which is a restrictive factor).
4. Insufficient understanding among a significant number of professors regarding the role and importance of entrepreneurship for learning outcomes and student competence development.
5. Low awareness of the importance of entrepreneurship education.
6. Financial limitations, outdated curricula, and certain resistant professors.

4.Discussion

Promotion of entrepreneurial learning in higher education is one of the six strategic priorities defined in the Strategy for Entrepreneurial Learning in the Education Systems in Bosnia and Herzegovina for the period 2012–2015, along with its accompanying Action Plan. However, only 20% of respondents in this study were familiar with the Strategy. All respondents who indicated familiarity with the Strategy were from faculties of economics. Fewer than half of the respondents considered themselves competent to deliver entrepreneurship education, with 12.9% stating that they feel competent but lack the opportunity to implement it. In total, only 30.9% reported both competence and active engagement in entrepreneurship education.

Encouragingly, 80% of respondents expressed interest in participating in some form of training on entrepreneurship education, while 54.5% had already attended such training.

When analysing only the responses from staff at faculties of economics, 46.6% considered themselves competent to teach entrepreneurship education, of which 11.1% reported not having the opportunity to implement it.

Based on these findings, several recommendations can be identified for relevant ministries and university management. These include the need for additional training of higher education staff in entrepreneurship education and for more effective communication of strategic documents related to entrepreneurship education in BiH. Considering the potential impact of extracurricular activities on students' entrepreneurial intentions [4][13], higher education institutions (HEIs) should also work to encourage academic staff to engage more in such activities, especially those that promote entrepreneurial behaviour.

Moreover, the main barriers to implementing entrepreneurship education in HEIs can also be viewed as areas for intervention, where institutions and their founders can jointly act. When designing strategies, it is necessary to consider existing challenges and obstacles to create space for improvement.

A total of 40 open-ended responses were collected, offering valuable insights into professors' and associates' perspectives on the benefits of implementing entrepreneurship education at their institutions. In addition to advantages, responses from staff at four public universities in BiH also provided insight into the challenges of implementation. These identified obstacles can simultaneously be seen as opportunities for HEIs and their founders to intervene strategically.

As for limitations and directions for future research, it is recommended to repeat the study with a focus on analysing the Priorities (2021–2030) instead of the earlier Strategy, which could contribute to enhancing the implementation of entrepreneurship education in higher education. A key limitation of this study is the relatively small sample size, which restricts the generalizability of results. This limitation can be addressed by expanding the sample to include a greater number of staff across various universities and faculties.

Future research should also include comparative analysis using data from countries with more developed and successful models of entrepreneurship education. Such an analysis would allow the identification of best practices and innovative approaches that could be adapted and applied in the BiH context.

5.Conclusion

Based on the research findings, key areas for the improvement of entrepreneurship education have been identified—areas in which higher education institutions (HEIs) should actively engage to foster the development of entrepreneurship education in Bosnia and Herzegovina. The main barriers to implementation, as reported by professors and associates, include a lack of financial resources, low awareness of the importance of entrepreneurship education, institutional inertia within HEIs, student passivity, insufficient training, outdated curricula, and even resistance from other faculty members. More than 50% of respondents do not consider themselves competent to deliver entrepreneurship education. Therefore, it is essential to raise awareness of its

importance through targeted training programs and the professional development of academic staff to improve their competencies in this field.

Efforts must also be made to revise and modernize curricula and syllabi within higher education institutions. Entrepreneurial learning should not be confined to higher education alone; rather, it is crucial to integrate it into primary and secondary education systems as well, in order to develop entrepreneurial culture and skills among young people from an early age. Strengthening cooperation between academia and the business sector is also essential, as it helps enhance students' practical skills and enables them to engage in solving real-world problems faced by companies. This cooperation may include student internships, joint projects, case study analyses, incubators, and similar initiatives.

Importantly, non-formal entrepreneurship education must not be overlooked. It should be further strengthened as it offers practical experience and fosters the development of entrepreneurial skills outside the formal education system.

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Arima Models in the Function of Forecasting Income of Extra-Budgetary Funds

Mukinović Samir

[1]Univerzitet Finra, Tuzla, Bosna I Hercegovina

E-mail: smukinovic@gmail.com

Abstract. Control of revenue collection for health care financiers is closely related to valid forecasts of revenue trends based on relevant time series. According to the above, the subject of the paper is the analysis of the efficiency of prognostic models for the time series of revenues of extrabudgetary funds, which have systemic components. The analysis aims to determine the effectiveness of selected statistical prognostic models for phenomena that have systemic components. The basic hypothesis of the work is that ARIMA models provide a reliable information base for planning the income of extra-budgetary funds.

1. Introduction

In today's world, discussions about how to rationalize healthcare spending are becoming increasingly frequent. One of the most pressing questions is why healthcare-related costs for insured individuals continue to rise year after year, and how these costs can be contained. On the other hand, there is significant interest in ensuring the necessary revenues to meet obligations arising from the provision of healthcare services. Monitoring healthcare expenditure and forecasting future spending is a highly complex task. Therefore, forecasting revenues and expenditures related to health insurance—along with the reliability of the methods used—is a key criterion and a matter of interest for stakeholders at both the micro and macro levels. At the micro level, these stakeholders primarily include health insurance funds or institutes as extra-budgetary funds, public healthcare institutions (such as health centers and hospitals), as well as pharmaceutical manufacturers and their representatives (wholesalers and pharmacies). Additionally, municipalities, cities, regions, or cantons—depending on the country's administrative structure—are involved. At the macro level, the key stakeholder is the state itself, including its institutions, agencies, and authorities, which should be responsible for developing and implementing appropriate health policies.

For forecasting the revenues and expenditures of health insurance institutes, which operate as extra-budgetary funds, both qualitative and quantitative—i.e., statistical forecasting methods and models—can be applied. The selection of an appropriate forecasting model, based on performance measures, determines the quality of the projection or forecast. Gaining knowledge in the field of statistical forecasting models, along with acquiring the skills and experience necessary to evaluate and select a representative forecasting model, becomes imperative for forecasting revenues and expenditures of extra-budgetary funds in the coming period.

In recent years, domestic scientific and research efforts have increasingly focused on health economics, pharmacoeconomics, and pharmacoepidemiology. A significant number of research results have been published on healthcare expenditure. However, studies that analyze time series related to the revenues and expenditures of health insurance institutes and those that focus on developing representative forecasting models for such data remain very rare.

2. Methodology and Research Objective

Forecasting revenues and expenditures related to health insurance is of great importance for all stakeholders in the healthcare system. In line with the subject and objective of the research, the main research hypothesis is as follows: "In forecasting the revenues of health insurance institutes, as extra-budgetary funds, ARIMA models provide reliable information on expected revenues within the forecasting horizon."

The data analysis is based on primary data regarding pharmaceutical expenditures, collected from the Health Insurance Institute of the Tuzla Canton. The data covers the period from January 1, 2017, to September 30, 2024. Given the subject, objective, and hypothesis of the research, the methodology is based on time series analysis, specifically using ARIMA models. To compare forecasting accuracy, the performance measures used include MAPE, MSE, and RMSE.

The theoretical significance of this research lies in providing a foundation for the proper selection and application of forecasting models for revenue and expenditure time series, with or without systematic components. From an empirical perspective, the contribution of this research is in developing forecasting models for revenues and expenditures that can be used in the formulation of healthcare policies and planning.

3. Time Series Analysis

3.1 Stationary and Non-Stationary Time Series

A time series is a sequence of ordered observations in relation to time. In essence, a time series represents the realization of a stochastic (random) process. "Time series are sequences of numerical data related to a phenomenon, arranged in chronological order at regular time intervals" [1]. The relationship between a time series and a stochastic

process is analogous to the relationship between a sample and a population in standard statistical inference theory. By analyzing a specific series, it is possible to gain insight into the characteristics of the underlying random process, just as sample data can be used to infer the characteristics of a population. A stochastic process is a sequence of random variables ordered in time. "There is no consensus in the literature on what exactly constitutes a time series" [2]. In addition to the aforementioned definition, many authors use the terms time series and stochastic process interchangeably. There are different criteria for classifying time series. An interval series is formed by aggregating frequencies, whereas in point-in-time series, there is no such aggregation. From the perspective of how the observed phenomenon is expressed, time series can be either original or derived (obtained by performing numerical operations on one or more original data series). Time series analysis is a subject of research across various fields and for different purposes. Time series analysis includes:

- description of the development of the phenomenon over time,
- explanation of the variation of the phenomenon over time using other variables,
- forecasting the future development of the phenomenon, and
- process control.

The key classification of time series, depending on whether their statistical properties change over time, is the division into:

- stationary**,** and
- non-stationary time series.

Ideja, zamisao o korištenju matematičkh modela da bi opisali ponašanje fizičke pojave je dobra zamisao. Posebno, moguće je izvesti model koji omogućava izračunati vrijednosti neke vremenski zavisne količine, približno tačno, u bilo kom trenutku vremena. Ako bi tačan izračun bio moguć, takav model bi u potpunosti bio deterministički. Vjerovatno ne postoji pojava koja je potpuno deterministička, zato što su mnogi faktori nepoznati. U mnogim problemima mi moramo uzeti u obzir fenomen vremenske zavisnosti, kao što je mjesečna prodaja novina ili potrošnja lijekova u kojima su mnogi faktori nepozanti. Za takve pojave nije moguće napisati model koji dozvoljava tačan izračun za buduće ponašanje pojave. Ali moguće napisati model koji se može koristiti za izračunati vjerovatnosti da će buduća vrijednost ležati između dvije određene granice. Takav model se zove model vjerovatnosti ili stohastički model.

3.2 Specifics of Accounting Recognition and Recording of Revenues and Expenditures of Extra-Budgetary Funds

The most important regulations governing the current budgetary accounting system in the Federation of Bosnia and Herzegovina—which also apply to extra-budgetary funds—are:

- Law on Budgets in the Federation of Bosnia and Herzegovina ("Official Gazette of the Federation of BiH", No. 19/06),

- Regulation on Budget Accounting in the Federation of Bosnia and Herzegovina ("Official Gazette of the Federation of BiH", No. 10/07),
- Rulebook on Financial Reporting and Annual Budget Settlement in the Federation of Bosnia and Herzegovina ("Official Gazette of the Federation of BiH", No. 17/05),
- Law on Accounting and Auditing in the Federation of Bosnia and Herzegovina ("Official Gazette of the Federation of BiH", No. 32/05),
- Laws on the Treasury in the Federation of Bosnia and Herzegovina ("Official Gazette of the Federation of BiH", Nos. 58/02, 19/03, and 79/07),
- Law on Internal Audit in the Public Sector in the Federation of Bosnia and Herzegovina ("Official Gazette of the Federation of BiH", No. 48/08),
- Relevant regulations for each level of government.

The provisions of these regulations apply to: the budgets of the Federation of BiH, cantons, cities, and municipalities; extra-budgetary fund budgets; and their users who operate under the treasury system.

The essence of the Law on Budgets is to promote precise budget planning in terms of revenues. The level of planned revenues is taken as a limiting factor in the planning of certain expenditures. The main principle of this law is the designated spending of funds within a clearly defined scope, in order to achieve realistic and economical budget planning.

The provisions of the aforementioned regulations apply to all legal entities within the general government sector, which for the purposes of this paper include: the budget of the Federation of BiH, budget users of the federal budget, extra-budgetary funds at the federation level, and the budgets of regional and local self-government units and their users [3].

3.3 Accounting System Based on the Modified Accrual Basis

In accordance with the provisions of the aforementioned regulations, which form the legal framework—specifically the Law on Budgets in the Federation of Bosnia and Herzegovina—the accounting system for budgets and extra-budgetary funds is based on the modified accrual basis. The recognition of revenues and inflows, as well as expenditures and outflows recorded in the general ledger of the budget, is carried out according to the modified accrual accounting principle. According to the modified accrual basis of accounting, revenues and inflows are recognized in the accounting period in which they are measurable and available.

The Law on Budget Accounting in the Federation of Bosnia and Herzegovina defines the meanings of the terms revenues, inflows, expenditures, and outflows. According to this law:

- Revenues include, without limitation, tax and non-tax revenues, and other revenues established by law or resulting from actions of budget institutions;
- Budget inflows are cash receipts from financial assets, non-financial assets, domestic and foreign support, and borrowing;

- Budget expenditures are prescribed by law and regulations issued under the law, related to activities, functions, and programs planned in the budget and financial plans of budget beneficiaries;
- Budget outflows are disbursements of cash for financial and non-financial assets and loan repayments.

In accordance with the provisions of the Rulebook on Budget Accounting in the Federation of Bosnia and Herzegovina, and the Analytical Chart of Accounts as its integral part, revenues are classified as:

- Tax revenues,
- Non-tax revenues,
- Current transfers (grants) received,
- Customs duties and other import charges, and special taxes on imported goods.

Since inflows, in addition to operating revenues, are also recognized, they are classified as:

- Capital inflows (from the sale of fixed assets, sale of federal commodity reserves, grants from non-governmental sources, and other capital inflows),
- Capital transfers (from abroad and from other levels of government),
- Repayments received on granted loans and returns on equity participation,
- Long-term loans and borrowings,
- Short-term loans and borrowings.

According to the modified accrual basis of accounting, expenditures and outflows are recognized in the accounting period in which the payment obligation arises.

4. ARIMA Models

4.1 Complex Forecasting Models

Data on phenomena in economics and other areas of research interest are very often collected as time series. For forecasting purposes, in addition to simple forecasting models, complex forecasting models are also used. Among the complex models are, of course, autoregressive moving average (ARMA) models and ARIMA models [4].

4.2 Analysis of Stationary Time Series

A stochastic process is considered stationary if its properties do not change over time. Stationary time series can be either strictly or weakly stationary. There are two main concepts of stationarity: the concept of strict stationarity (also known as strong stationarity or stationarity in the narrow sense), and the concept of weak stationarity (also referred to as wide-sense stationarity, covariance stationarity, or second-order stationarity).

ARMA models represent a very important class of linear models for analyzing stationary time series. Within this group, the most significant models include: the pure

random process model, autoregressive (AR) models, moving average (MA) models, and the mixed ARMA model, which combines the two aforementioned types.

4.3 Mixed ARMA Models

We have already emphasized that two important properties of stochastic processes are stationarity and invertibility. Stationarity implies that the process has an MA(∞) representation, while invertibility means that the process has an AR(∞) representation. In other words, a finite-order AR(p) model is equivalent to an infinite moving average model, i.e., an MA(∞) model. Similarly, a finite-order MA(q) model is equivalent to an infinite autoregressive model, i.e., an AR(∞) model. Typically, a sufficiently large lag length is chosen to approximate AR(∞) or MA(∞) with finite-order AR or MA models of order p or q. As a result, these models may involve a large number of estimated parameters, which can directly reduce the efficiency of the estimation. To avoid this issue, models that incorporate terms from both AR and MA models have been developed. These are defined as ARMA(p, q) models [5]. ARMA models simultaneously include components from autoregressive models and moving average models. The model can be expressed as:

$$\phi(B)Y_t = \theta_0 + \theta(B)\epsilon_t \quad (1)$$

A highly desirable property of an ARMA(p, q) process is stationarity and invertibility. For the process to be stationary, all characteristic roots of the polynomial ϕ(B) must lie outside the unit circle. For the process to be invertible, all characteristic roots of the polynomial θ(B) must also lie outside the unit circle. In addition, the polynomials ϕ(B) and θ(B) must not have any common factors.

In research and time series analysis, the appropriate ARMA(p, q) model is selected by examining the behavior of the autocorrelation function (ACF) and the partial autocorrelation function (PACF). The decay of the ACF in an ARMA(p, q) process typically starts at lag q. The decay of the PACF usually begins at lag p. If the process is an ARMA(1, 1), the equation is as follows:

$$Y_t = \varphi_1 Y_{t-1} + \varepsilon_t - \theta_1 \epsilon_{t-1} \quad (2)$$

4.4 Performance Measures of Forecasting Models

In forecasting, the goal is to achieve the highest possible accuracy of the prediction. Forecasting performance measures are generally divided into absolute and relative measures. Among others, performance measures include: forecasting error, percentage forecasting error, mean forecasting error, and mean absolute percentage error (MAPE) [6].

$$E_t = Y_t - F_t \quad (3)$$

where Yi is the actual value of the observed phenomenon, and Fi is the forecasted value of the observed phenomenon.

The percentage forecasting error (PE) is calculated using the following formula:

$$PE_t = \frac{Y_t - F_t}{Y_t} \times 100 \quad (4)$$

The mean absolute deviation (MAD) is calculated using the following formula:

$$MAD = \frac{\sum_{t=1}^{T} |Y_t - F_t|}{T} \quad (5)$$

where T is the number of pairs of actual and forecasted values of the observed phenomenon.

The mean absolute percentage error (MAPE) is calculated using the following formula:

$$MAPE = \frac{1}{T} \sum_{t=1}^{T} \left| \frac{Y_t - F_t}{Y_t} \right| \times 100 \quad (6)$$

According to the above, all forecasting performance indicators are based on the use of forecasted and actual values of the observed phenomenon. Based on these indicators, one can assess the accuracy of the forecast, and accordingly make a decision on whether to use, abandon, or possibly modify the forecasting method.

5. Research Results

To forecast the revenues of the extra-budgetary fund, i.e., the health insurance institute, we present below the research results obtained using ARIMA models.

5.1. Information on the Data Used in the Research

Below, we provide additional information about the data used in the research. Quarterly revenue data over a period of 8 years, from 2017 to 2024, were collected from the official website of the Health Insurance Institute of Tuzla Canton. For the purpose of analysis, in addition to the original time series, we also generated the first difference. The quarterly revenue trends during the analyzed period, along with all relevant transformations of the series, are presented in the following figures.

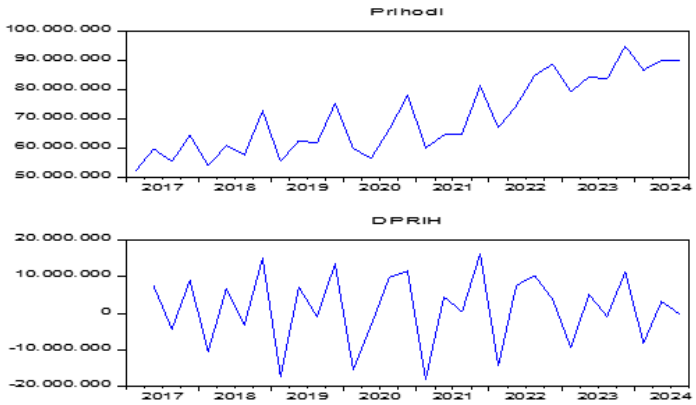
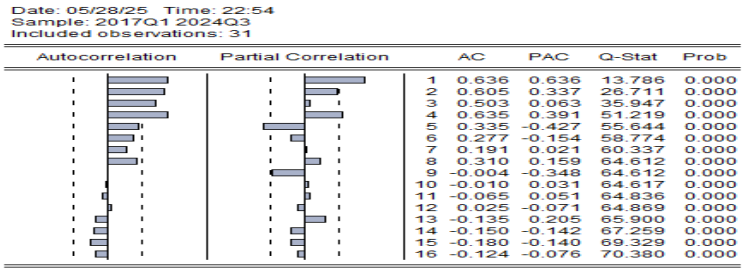


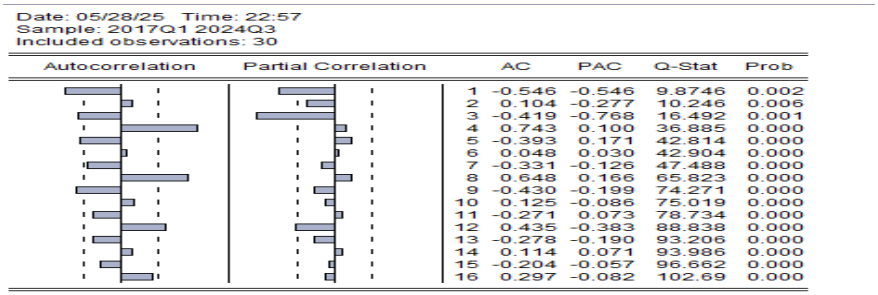
Figure 1: Revenue Trends During the Analyzed Period – Original Series and First Difference

An overview of the graphical representation of revenue trends over time, based on the original series, indicates a slightly increasing trend. The first difference appears relatively stable and oscillates around a zero mean. It resembles a stationary series with a few non-standard observations. As part of the preliminary analysis, it is very important to examine the behavior of the autocorrelation function (ACF) and partial autocorrelation function (PACF).



	AC	PAC	Q-Stat	Prob
1	0.636	0.636	13.786	0.000
2	0.605	0.337	26.711	0.000
3	0.503	0.063	35.947	0.000
4	0.635	0.391	51.219	0.000
5	0.335	-0.427	55.644	0.000
6	0.277	-0.154	58.774	0.000
7	0.191	0.021	60.337	0.000
8	0.310	0.159	64.612	0.000
9	-0.004	-0.348	64.612	0.000
10	-0.010	0.031	64.617	0.000
11	-0.065	0.051	64.836	0.000
12	0.025	-0.071	64.869	0.000
13	-0.135	0.205	65.900	0.000
14	-0.150	-0.142	67.259	0.000
15	-0.180	-0.140	69.329	0.000
16	-0.124	-0.076	70.380	0.000

Figure 2: Correlogram of the Original Series



	AC	PAC	Q-Stat	Prob
1	-0.546	-0.546	9.8746	0.002
2	0.104	-0.277	10.246	0.006
3	-0.419	-0.768	16.492	0.001
4	0.743	0.100	36.885	0.000
5	-0.393	0.171	42.814	0.000
6	0.048	0.030	42.904	0.000
7	-0.331	-0.126	47.488	0.000
8	0.648	0.166	65.823	0.000
9	-0.430	-0.199	74.271	0.000
10	0.125	-0.086	75.019	0.000
11	-0.271	0.073	78.734	0.000
12	0.435	-0.383	88.838	0.000
13	-0.278	-0.190	93.206	0.000
14	0.114	0.071	93.986	0.000
15	-0.204	-0.057	96.662	0.000
16	0.297	-0.082	102.69	0.000

Figure 3: Correlogram of the First Difference

The correlogram of revenues based on the original time series suggests that the series may be non-stationary. The values of the standard autocorrelation coefficients in the original time series are close to 1. This is further supported by the shape of the partial correlogram.

Next, we apply the unit root test, specifically the Dickey-Fuller (DF) test. As most real-world time series typically exhibit a trend, we begin the unit root test using the τt (tau-t) specification. The test evaluates whether the movement of revenues in the extra-budgetary fund depends on a constant, a linear trend, and the lagged value of the series at time t–1. The test results are presented in the following table. The test is conducted at a 5.00% level of significance (risk).

Null Hypothesis: PRIHODI has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 3 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-1.077541	0.9145
Test critical values:	1% level	-4.339330	
	5% level	-3.587527	
	10% level	-3.229230	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(PRIHODI)
Method: Least Squares
Date: 05/28/25 Time: 22:59
Sample (adjusted): 2018Q1 2024Q3
Included observations: 27 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PRIHODI(-1)	-0.325247	0.301842	-1.077541	0.2935
D(PRIHODI(-1))	-0.691982	0.253807	-2.726407	0.0126
D(PRIHODI(-2))	-0.724231	0.204665	-3.538608	0.0019
D(PRIHODI(-3))	-0.755732	0.141541	-5.339319	0.0000
C	16482335	15146152	1.088219	0.2888
@TREND("2017Q1")	619705.9	375546.5	1.650144	0.1138

R-squared	0.821653	Mean dependent var	935899.8
Adjusted R-squared	0.779189	S.D. dependent var	10180774
S.E. of regression	4784000.	Akaike info criterion	33.79258
Sum squared resid	4.81E+14	Schwarz criterion	34.08055
Log likelihood	-450.1999	Hannan-Quinn criter.	33.87821
F-statistic	19.34955	Durbin-Watson stat	1.805849
Prob(F-statistic)	0.000000		

Figure 4: Unit Root Test on the Original Time Series

Since the calculated value of the ADF(3) test statistic is greater than the critical value at the 5% significance level, i.e., –1.077 > –3.587, we cannot reject the null hypothesis of non-stationarity in the time series. Therefore, the revenue time series of the extra-budgetary fund (Health Insurance Institute of Tuzla Canton) is a non-stationary time series around a trend.

This is the final conclusion, provided that including the trend in the model is justified, i.e., that applying the tau-t statistic was appropriate. Whether a deterministic trend should be included in the model is tested using the Stock-Watson (SW) test. The results of the test regarding the significance of the trend in the level series, and the significance of the constant in its first difference, are shown in the following table.

Dependent Variable: DPRIH
Method: Least Squares
Date: 05/28/25 Time: 23:19
Sample (adjusted): 2017Q2 2024Q3
Included observations: 30 after adjustments
HAC standard errors & covariance (Bartlett kernel, Newey-West fixed bandwidth = 4.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1249032.	494477.5	2.525964	0.0173

R-squared	0.000000	Mean dependent var	1249032.
Adjusted R-squared	0.000000	S.D. dependent var	9875947.
S.E. of regression	9875947.	Akaike info criterion	35.08187
Sum squared resid	2.83E+15	Schwarz criterion	35.12857
Log likelihood	-525.2280	Hannan-Quinn criter.	35.09681
Durbin-Watson stat	3.077855		

Figure 5: Test of Trend Significance

Among the results shown in the table above is the calculated (empirical) value of t=2.525. If the test is conducted at a 5% significance level (0.05), the critical (tabulated) value is tα; (n−2)=t ·0.05; Since t>tα, we conclude, at the 5% significance level (risk),

that the constant is statistically significant in the model. Given that the constant is statistically significant, it is justified to include a deterministic trend in the model, i.e., the use of the τt (tau-t) statistic is appropriate. An equivalent conclusion can be reached using the p-value approach. Since the p-value is less than α ($p < 0.05$), we conclude that the constant in the first difference, i.e., the trend in the level of the time series, is statistically significant.

Since the original revenue time series is non-stationary, we next examine the stationarity of the first difference of the revenue series. Therefore, we proceed with the unit root test for the first difference of revenue (DPRIH).

Null Hypothesis: DPRIH has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 2 (Automatic - based on SIC, maxlag=7)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-12.22855	0.0000
Test critical values:	1% level	-4.339330	
	5% level	-3.587527	
	10% level	-3.229230	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(DPRIH)
Method: Least Squares
Date: 05/28/25 Time: 23:28
Sample (adjusted): 2018Q1 2024Q3
Included observations: 27 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DPRIH(-1)	-3.669881	0.300108	-12.22855	0.0000
D(DPRIH(-1))	1.733402	0.225656	7.681627	0.0000
D(DPRIH(-2))	0.844027	0.115832	7.286670	0.0000
C	336779.7	2220441.	0.151672	0.8808
@TREND("2017Q1")	236079.4	119955.4	1.968060	0.0618

R-squared	0.939501	Mean dependent var	-341984.3
Adjusted R-squared	0.928501	S.D. dependent var	17956668
S.E. of regression	4801483.	Akaike info criterion	33.77232
Sum squared resid	5.07E+14	Schwarz criterion	34.01229
Log likelihood	-450.9264	Hannan-Quinn criter.	33.84368
F-statistic	85.41049	Durbin-Watson stat	1.852718
Prob(F-statistic)	0.000000		

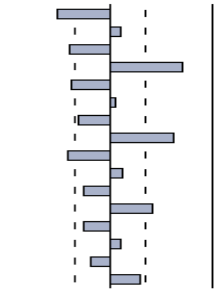
Figure 6: Unit Root Test on the First Difference

Since the calculated value of the ADF (2) test statistic is greater than the critical value at the 5% significance level, i.e., $-12.228 > -3.587$, we can reject the null hypothesis of non-stationarity. Therefore, the first difference of the revenue time series of the extra-budgetary fund (Health Insurance Institute of Tuzla Canton) is a stationary time series around a trend. Accordingly, the revenue time series of the extra-budgetary fund has exactly one unit root.

Having confirmed the stationarity of the first difference of revenue, we proceed to model the first difference of the revenue time series.

To determine the order of the autoregressive component and the moving average component, we must examine the behavior of the autocorrelation function (ACF) and partial autocorrelation function (PACF).

Date: 05/28/25 Time: 23:33
Sample: 2017Q1 2024Q3
Included observations: 30



	AC	PAC	Q-Stat	Prob
1	-0.546	-0.546	9.8746	0.002
2	0.104	-0.277	10.246	0.006
3	-0.419	-0.768	16.492	0.001
4	0.743	0.100	36.885	0.000
5	-0.393	0.171	42.814	0.000
6	0.048	0.030	42.904	0.000
7	-0.331	-0.126	47.488	0.000
8	0.648	0.166	65.823	0.000
9	-0.430	-0.199	74.271	0.000
10	0.125	-0.086	75.019	0.000
11	-0.271	0.073	78.734	0.000
12	0.435	-0.383	88.838	0.000
13	-0.278	-0.190	93.206	0.000
14	0.114	0.071	93.986	0.000
15	-0.204	-0.057	96.662	0.000
16	0.297	-0.082	102.69	0.000

Figure 7: Correlogram of the First Difference

The partial autocorrelation coefficient and autocorrelation coefficients are statistically significant at the first, third, and fourth lags. The AR(p) model class is characterized by a partial autocorrelation function where the coefficients take non-zero values for lags equal to or less than the order of the process p. Although the moving average (MA) components are autocorrelated, the behavior of the autocorrelation functions—both standard and partial—is quite different from that of an autoregressive model. The sample autocorrelation function (SACF) becomes insignificant or drops to zero after q time lags.

The analysis of the sample partial autocorrelation function (SPACF) is used to determine the order q of an MA model. "If the SACF values are statistically significant only for lags less than or equal to q, and approximately zero for larger lags (i.e., they deviate from the expected value by less than two standard errors), and if the SPACF values gradually decay with lag k, the appropriate model is an MA(q) model [7]."

Based on the above, we begin the modeling process with an AR(1) and MA(1) model.

Dependent Variable: DPRIH
Method: ARMA Maximum Likelihood (OPG - BHHH)
Date: 05/28/25 Time: 23:35
Sample: 2017Q2 2024Q3
Included observations: 30
Convergence achieved after 14 iterations
Coefficient covariance computed using outer product of gradients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1203518.	319990.4	3.761107	0.0009
AR(1)	-0.194378	0.217901	-0.892049	0.3805
MA(1)	-0.781675	0.194505	-4.018799	0.0004
SIGMASQ	4.59E+13	1.73E+13	2.661088	0.0132

R-squared	0.513005	Mean dependent var	1249032.
Adjusted R-squared	0.456813	S.D. dependent var	9875947.
S.E. of regression	7278691.	Akaike info criterion	34.60455
Sum squared resid	1.38E+15	Schwarz criterion	34.79138
Log likelihood	-515.0683	Hannan-Quinn criter.	34.66432
F-statistic	9.129549	Durbin-Watson stat	2.080380
Prob(F-statistic)	0.000268		

Inverted AR Roots	-.19
Inverted MA Roots	.78

Figure 8: ARIMA Model with Estimated Parameters

The following is a graphical representation of the actual and forecasted values of the first difference of revenue of the extra-budgetary fund using the ARIMA(1, 1, 1) model described above.

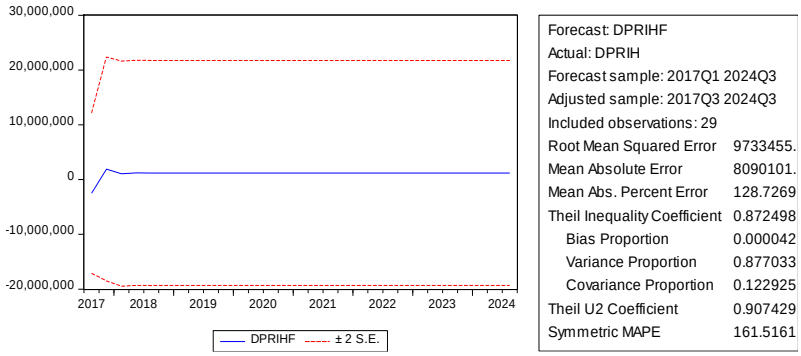


Figure 9: Actual and Forecasted Revenue Values Using the ARIMA(1,1,1) Model

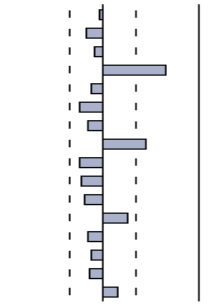
The results show that the coefficient for MA(1) is statistically significant ($p < 0.05$; $p < 0.10$). The coefficient of determination (R^2) for the estimated model is 0.513, indicating a moderate level of fit. This means that 51.30% of the total variation is explained by the model. The adjusted coefficient of determination (Adjusted R^2) is 0.456. This suggests that there is a statistically significant relationship between the analyzed variables and that the model is relatively good.

Among the results in the table is also the estimate of the standard error of the regression (S.E. of regression), which amounts to 0.727. This indicates the average deviation of the observed values from the predicted values.

In addition to the standard error of the regression, the table also presents the mean value (Mean dependent var) and the standard deviation (S.D. dependent var) of the dependent variable, as well as information criteria: Akaike, Schwarz (Bayesian), and Hannan-Quinn.

The residuals are examined to check for the presence of autocorrelation.

Date: 05/28/25 Time: 23:36
Sample: 2017Q1 2024Q3
Included observations: 30
Q-statistic probabilities adjusted for 2 ARMA terms



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.048	-0.048	0.0751	
		2	-0.172	-0.175	1.0924	
		3	-0.095	-0.117	1.4151	0.234
		4	0.681	0.667	18.526	0.000
		5	-0.116	-0.194	19.046	0.000
		6	-0.253	-0.175	21.602	0.000
		7	-0.157	-0.081	22.625	0.000
		8	0.466	-0.015	32.108	0.000
		9	-0.259	-0.291	35.179	0.000
		10	-0.230	0.073	37.725	0.000
		11	-0.193	-0.125	39.605	0.000
		12	0.272	-0.218	43.561	0.000
		13	-0.169	0.245	45.172	0.000
		14	-0.126	0.033	46.122	0.000
		15	-0.148	-0.164	47.522	0.000
		16	0.156	-0.034	49.197	0.000

Figure 10: Correlogram of Residuals

A review of the correlogram reveals the presence of residual autocorrelation. The values of the autocorrelation and partial autocorrelation coefficients are statistically significant at lag k = 4. For this reason, a fourth-order MA component is introduced into the model. The model is thus extended to include MA(4). This leads to the model specification presented in the following table. An inspection of the correlogram indicates the presence of residual autocorrelation. The autocorrelation and partial autocorrelation coefficients are statistically significant at lag k = 4. Consequently, a moving average component of order 4 (MA(4)) is introduced into the model. The model is thereby extended to include this component, resulting in the specification presented in the following table.

Dependent Variable: DPRIH
Method: ARMA Maximum Likelihood (OPG - BHHH)
Date: 05/28/25 Time: 23:37
Sample: 2017Q2 2024Q3
Included observations: 30
Failure to improve objective (non-zero gradients) after 30 iterations
Coefficient covariance computed using outer product of gradients

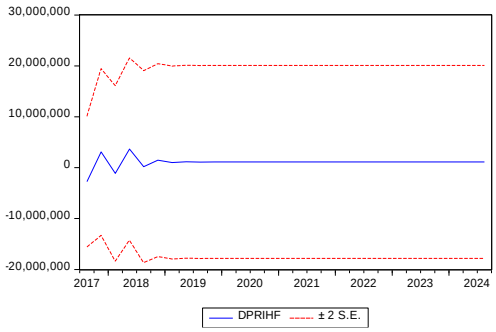
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1117630.	858990.2	1.301097	0.2051
AR(1)	-0.366397	0.253714	-1.444134	0.1611
MA(1)	-0.518874	0.196420	-2.641658	0.0140
MA(4)	0.671172	1.835415	0.365679	0.7177
SIGMASQ	2.98E+13	1.54E+13	1.932028	0.0648

R-squared	0.684173	Mean dependent var	1249032.
Adjusted R-squared	0.633641	S.D. dependent var	9875947.
S.E. of regression	5977673.	Akaike info criterion	34.37392
Sum squared resid	8.93E+14	Schwarz criterion	34.60746
Log likelihood	-510.6089	Hannan-Quinn criter.	34.44863
F-statistic	13.53934	Durbin-Watson stat	2.106886
Prob(F-statistic)	0.000005		

Inverted AR Roots	-.37			
Inverted MA Roots	.79-.61i	.79+.61i	-.53+.63i	-.53-.63i

Figure 11: Model with Estimated Parameters

The following is a graphical representation of the actual and forecasted values of the first difference of revenue of the extra-budgetary fund using the ARIMA(1, 1, 4) model described above.



Forecast: DPRIHF
Actual: DPRIH
Forecast sample: 2017Q1 2024Q3
Adjusted sample: 2017Q3 2024Q3
Included observations: 29

Root Mean Squared Error	9545656.
Mean Absolute Error	7834674.
Mean Abs. Percent Error	122.1804
Theil Inequality Coefficient	0.842777
Bias Proportion	0.000000
Variance Proportion	0.844188
Covariance Proportion	0.155812
Theil U2 Coefficient	0.912002
Symmetric MAPE	157.0317

Figure 12: Actual and Forecasted Revenue Values Using the ARIMA(1,1,4) Model

Since the coefficients for AR(1) and MA(4) are statistically insignificant, as $P > 0.05$, they are excluded from the model, while the model is extended with an MA(4) component. This results in the model specification presented in the following table.

Dependent Variable: DPRIH
Method: ARMA Maximum Likelihood (OPG - BHHH)
Date: 05/28/25 Time: 23:42
Sample: 2017Q2 2024Q3
Included observations: 30
Convergence achieved after 15 iterations
Coefficient covariance computed using outer product of gradients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1176101.	580981.0	2.024337	0.0533
AR(4)	0.730635	0.152328	4.796452	0.0001
MA(1)	-0.793229	0.131948	-6.011703	0.0000
SIGMASQ	2.04E+13	4.66E+12	4.378200	0.0002

R-squared	0.783755	Mean dependent var	1249032.
Adjusted R-squared	0.758804	S.D. dependent var	9875947.
S.E. of regression	4850245.	Akaike info criterion	33.86259
Sum squared resid	6.12E+14	Schwarz criterion	34.04942
Log likelihood	-503.9388	Hannan-Quinn criter.	33.92236
F-statistic	31.41141	Durbin-Watson stat	2.003218
Prob(F-statistic)	0.000000		

Inverted AR Roots	.92	.00-.92i	.00+.92i	-.92
Inverted MA Roots	.79			

Figure 13: Model with Estimated Parameters

The residuals are examined to determine whether residual autocorrelation is still present.

Date: 05/28/25 Time: 23:43
Sample: 2017Q1 2024Q3
Included observations: 30
Q-statistic probabilities adjusted for 2 ARMA terms

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.016	-0.016	0.0087	
		2	0.065	0.065	0.1543	
		3	0.060	0.062	0.2828	0.595
		4	-0.109	-0.112	0.7222	0.697
		5	0.075	0.064	0.9355	0.817
		6	-0.218	-0.210	2.8390	0.585
		7	-0.027	-0.025	2.8701	0.720
		8	0.129	0.144	3.5987	0.731
		9	-0.306	-0.289	7.8852	0.343
		10	0.007	-0.047	7.8878	0.445
		11	-0.124	-0.084	8.6607	0.469
		12	-0.036	-0.036	8.7312	0.558
		13	0.028	-0.036	8.7751	0.643
		14	-0.009	0.096	8.7803	0.722
		15	-0.033	-0.205	8.8519	0.784
		16	-0.001	-0.038	8.8519	0.840

Figure 14: Correlogram of Residuals

A review of the residual correlogram shows that there is no residual autocorrelation, indicating that we have achieved "white noise." Finally, the model has an ARIMA (4, 1, 1) specification. This is also supported by the low values of the Ljung-Box statistic and p-values less than 0.05 (5% significance level).

The following is a graphical representation of the actual and forecasted values of the first difference of revenue of the extra-budgetary fund using the ARIMA(4, 1, 1) model described above.

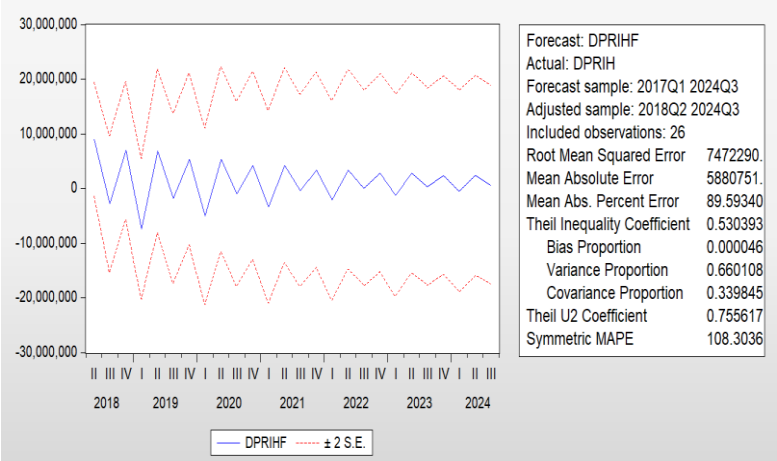


Figure 15: Actual and Forecasted Revenue Values Using the ARIMA(4,1,1) Model

After estimating the model parameters, during the model adequacy testing phase, in addition to checking for residual autocorrelation, it is necessary to assess the model's fit to the data. It must be verified whether the movement of the revenue time series of the extra-budgetary fund is well approximated by the specified AR model. In other words, it must be checked whether the residuals are normally distributed. The results of the Jarque-Bera test (JB test) are presented in the following figure.

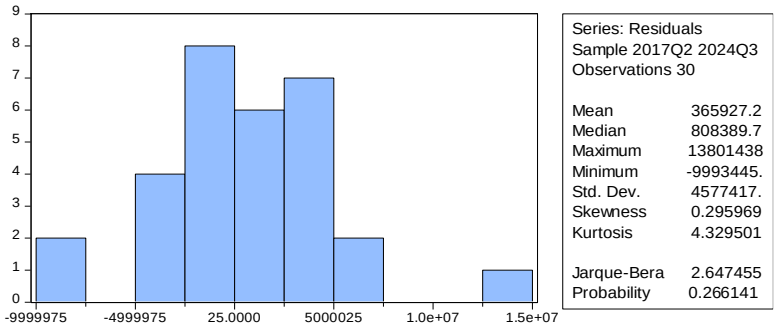


Figure 16: Normality of Residuals

The aforementioned test is used to examine whether the empirical distribution of residuals deviates from a normal distribution. The null hypothesis is defined as the empirical distribution of residuals being consistent with a normal distribution. If the calculated values of the JB test are lower than the corresponding critical values of the chi-squared (χ^2) test with 2 degrees of freedom and at the chosen significance level, the null hypothesis of normality of residuals is not rejected.

An equivalent conclusion can also be reached using the corresponding p-value—if the p-value is greater than the significance level (α) at which the test is conducted, the null hypothesis is likewise not rejected.

The following table presents the forecasting accuracy measures of the selected ARIMA forecasting models.

Table 1: Efficiency Measures of Selected Forecasting Models for the Stationary Time Series

	FORECASTING MODELS		
	ARIMA (1,1,1)	ARIMA (1,1,4)	ARIMA (4, 1, 1)
MAPE	128,72	122,18	89,53
MSE	3.119,84	3.089,61	2.733,54
RMSE	9.733.455,00	9.545.696.00	7.472.290,00

Based on the accuracy measures MAPE, MSE, and RMSE, the final selected model is a complex forecasting model with an ARIMA(4,1,1) specification. The model with estimated parameters can be written as follows:

$$X_t = 1.176.101{,}00 + 0{,}730 * X_{t-4} + e_t - 0{,}793\, e_{t-1}$$

SIC (Schwarz Information Criterion) = 34.049

SE (Standard Error of the Regression) = 33.922

JB = 2.467 (P = 0.266 → P > 0.05)

6. Conclusion

By modeling the revenues of the extra-budgetary fund using the ARIMA model, it is evident that ARIMA models provide a reliable informational basis for revenue planning of the mentioned fund. Accurate revenue forecasts for extra-budgetary funds are of great importance to all stakeholders in the health insurance system—particularly to healthcare and insurance service users, service providers, and especially payers.

Based on the values of MAPE, MSE, and RMSE, the final selected model is a complex forecasting model with an ARIMA(4,1,1) specification. Since this model includes an AR(4) component and the revenues are quarterly, it is evident that revenues in any given quarter of the upcoming year depend on the revenues of the extra-budgetary fund in the same quarter of the previous year.

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European Union Action on Climate Change: A Reflection on Chapter 27 and the Position of Bosnia and Herzegovina

Ajna Jodanović[1*], Jasmin Musić[2]

[1] Faculty of Law, University of Bihać, Bihać, Bosnia and Herzegovina
[2] Major, Municipality of Ključ, Ključ, Bosnia and Herzegovina

E-mail: ajna_x@hotmail.com

Abstract. This paper provides a critical examination of the European Union's climate policy framework—anchored in the European Green Deal—and its operationalization through Chapter 27: Environment and Climate Change in the EU enlargement context. While the EU has established a sophisticated architecture of legal obligations, institutional mechanisms, and financial instruments to pursue climate neutrality by 2050, candidate countries are expected to undertake profound structural reforms to align with the acquis communautaire. Chapter 27 is emblematic of this challenge, representing one of the most technically complex and politically sensitive components of the accession process. Through a focused case study of Bosnia and Herzegovina, the paper explores the country's limited progress in fulfilling the legal, administrative, and strategic requirements of Chapter 27. It identifies major deficiencies in the existing governance framework, including the absence of a comprehensive climate law, institutional fragmentation across multiple governance tiers, insufficient technical and human resources, and an enduring lack of political ownership of the climate agenda. These obstacles are not simply procedural; they reflect deeper systemic weaknesses embedded in the country's post-conflict constitutional and administrative structure.

The analysis concludes by outlining a set of reform priorities essential to closing the climate alignment gap. These include enacting a unified legal framework for climate policy, empowering national coordinating institutions—particularly the Ministry of Foreign Trade and Economic Relations (MOFTER)—and strengthening inter-entity coordination and stakeholder engagement. Finally, the study underscores the critical role of EU support mechanisms such as IPA III, the Green Agenda, and the Western Balkans Investment Framework in enabling credible and sustained transformation. Aligning with Chapter 27 is thus not merely a condition for EU membership, but a necessary foundation for Bosnia and Herzegovina's long-term environmental resilience and development.

Keywords: Chapter 27, EU enlargement, climate policy, environmental governance, Bosnia and Herzegovina, institutional reform, acquis alignment; Western Balkans.

1. Introduction

The growing urgency of climate change has redefined the normative and institutional priorities of the European Union, positioning climate policy as a central pillar of its internal development and external relations. Within this strategic orientation, the European Green Deal represents a transformative framework aimed at achieving climate neutrality by 2050, supported by a suite of binding legal instruments, sectoral policies, and financial mechanisms. For countries aspiring to EU membership, aligning with this acquis is not only a political commitment but a complex legal and administrative endeavour—reflected most clearly in Chapter 27 – Environment and Climate Change.

This chapter remains one of the most expansive and technically demanding within the EU accession process, encompassing over 200 legal acts and requiring significant reform across governance, legislation, and enforcement systems. The expectations placed on candidate countries include the full transposition of EU climate law, functional institutional structures, and demonstrated implementation capacity—benchmarked through screening, action planning, and monitoring cycles.

This paper explores the structure and function of EU climate policy, the strategic weight of Chapter 27 within the enlargement process, and the specific challenges facing Bosnia and Herzegovina. Despite its formal accession aspirations, Bosnia and Herzegovina faces serious obstacles to environmental convergence: a fragmented constitutional system, the absence of a comprehensive climate law, weak inter-institutional coordination, and limited political ownership of climate objectives. Through an integrated policy and institutional analysis, this study identifies core deficiencies and outlines reform priorities critical to closing the alignment gap with the EU climate acquis.

2. The European Union's Climate Framework and Chapter 27 in the Accession Context

The European Union has positioned itself as a global forerunner in confronting the challenges posed by climate change, advancing a sophisticated and multidimensional legal and policy architecture aimed at fostering both environmental sustainability and long-term economic resilience. At the heart of this comprehensive framework lies the European Green Deal—a transformative strategy that articulates the Union's commitment to achieving climate neutrality by 2050, while also embedding principles of equity and inclusiveness in the transition toward a low-carbon economy.

To translate this vision into concrete outcomes, the EU has adopted an extensive suite of binding legal instruments, dedicated funding mechanisms, and institutional arrangements designed to drive emission reductions, facilitate energy transformation, and support regions most affected by the ecological transition. Within the context of the Union's enlargement policy, these commitments extend beyond the current Member States: candidate countries are likewise expected to align their national systems with the evolving climate acquis.

In this regard, Chapter 27 – Environment and Climate Change occupies a critical position within the accession process, representing not only a cornerstone of EU conditionality but also one of the most comprehensive and technically demanding chapters. Compliance with its provisions requires far-reaching legislative harmonization, the development of robust institutional capacities, and effective inter-sectoral coordination. This chapter therefore examines the architecture of EU climate policy, the intricate scope of Chapter 27, and the core obligations imposed on accession countries—particularly as articulated within the strategic framework of Cluster 4: Green Agenda and Sustainable Connectivity.

2.1. Legal Instruments, Institutional Responsibilities, and Candidate Country Obligations

The European Union has developed a comprehensive, multi-layered approach to tackling climate change—rooted in the landmark European Green Deal. This strategy sets the ambitious goal of achieving climate neutrality by 2050, along with a binding 55% reduction in greenhouse gas emissions by 2030 (compared to 1990 levels) [1].

The framework includes:

1. EU Climate Law, which legally enshrines targets for 2030 and 2050 [2].
2. Core instruments:
    a. Emissions Trading System (ETS) [3];
    b. Effort Sharing Regulation (for non-ETS sectors) [4];
    c. LULUCF Regulation (governing land use and forestry) [5];
    d. Directives on energy efficiency, renewable energy, and methane emissions [6].

Supporting funding schemes such as the Just Transition Fund and the Social Climate Fund, designed to ensure a fair transition for all EU regions [7].

The implementation and oversight of these policy instruments fall primarily under the responsibility of key EU institutions, most notably the European Commission—through its Directorate-General for Climate Action (DG CLIMA)—and the European Environment Agency, with coordination facilitated by the EU budget and various recovery and support mechanisms.

Chapter 27 is a cornerstone in the EU accession framework, encompassing environmental and climate legislation across more than 200 legal acts. Sectors include air, water, waste management, industrial emissions, chemicals, biodiversity, and significantly, climate change [8].

It stands out as one of the most demanding and resource-intensive chapters, requiring extensive legal reforms, upgraded enforcement systems, and the building of administrative capacity in candidate countries [9].

Candidate states must:

1. Fully transpose EU environmental laws.
2. Establish adequate monitoring, reporting, and enforcement mechanisms.
3. Align with cross-cutting EU principles such as the polluter-pays**,** precautionary, and environmental integration principles [10].

Under the EU's revised enlargement methodology, Cluster 4 – which includes Chapter 27 (Environment and Climate Change), Chapter 14 (Transport), Chapter 15 (Energy), and Chapter 21 (Trans-European Networks) – is recognized as a central pillar of the Green Agenda and sustainable integration for candidates aspiring to EU membership [11].

As the first formal step, candidate countries undergo a detailed screening process to assess alignment with EU law, institutional preparedness, and implementation capacity. This involves technical discussions, bilateral exchanges, and identifies legal and structural gaps within the environmental acquis [12].

In Albania's case, this process was completed with the Cluster 4 screening report issued in Tirana on 28 January 2025, explicitly pinpointing both sector-specific challenges and administrative limitations.

Following screening, each country must develop an action plan outlining detailed obligations, responsible institutions, and timelines for achieving compliance across all relevant acquis sub-chapters. Montenegro's Chapter 27 plan, for instance, enumerated 251 specific commitments, reflecting the complexity and breadth of environmental reforms required [13].

In the final stage of the process, the European Union provides comprehensive support to candidate countries through financial mechanisms—such as IPA III and the Western Balkans Investment Framework—as well as through technical assistance tailored to institutional needs. In parallel, the alignment process is subject to continuous monitoring, most notably through annual progress reports. This multidimensional support framework is essential to transform formal legislative harmonization into concrete and sustainable implementation at the national level.

The European Union's climate policy—rooted in the overarching vision of the European Green Deal and supported by a broad array of legal, strategic, and financial instruments—embodies a profound and sustained commitment to long-term environmental stewardship and climate resilience. Within the enlargement framework, Chapter 27: Environment and Climate Change stands as a central and particularly demanding component, offering candidate countries a comprehensive yet intricate roadmap for the approximation of national frameworks with the EU acquis. Its implementation necessitates not only the formal transposition of legislation but also the establishment of functional institutional structures, cross-sectoral policy integration, and sustained capacity development at all levels of governance.

The trajectories of countries such as Albania and Montenegro exemplify both the complexity of the alignment process and the systematic nature of EU support mechanisms. These include structured screening procedures, detailed action plans, targeted funding instruments, and recurring progress evaluations—each serving as a critical pillar in the broader architecture of environmental integration. By contrast, Bosnia and Herzegovina remains at an earlier and more fragmented phase of alignment, impeded by overlapping institutional jurisdictions, the absence of a coherent and comprehensive climate change law, and a notable lack of strategic coordination across governance levels.

Despite isolated advances—such as the adoption of selected policy documents and participation in regional cooperation frameworks—substantial challenges persist.

These include insufficient harmonization with EU norms, weak enforcement structures, and an overarching lack of political consensus and administrative continuity.

Against this backdrop, genuine progress toward Chapter 27 alignment will require more than technical compliance; it demands a recalibration of Bosnia and Herzegovina's institutional architecture. This entails legal reform, strengthened inter-entity collaboration, and the articulation of a unified national climate agenda. Fulfilment of these conditions is not merely a prerequisite for EU accession, but a foundational step toward ensuring environmental sustainability and climate resilience in the decades ahead.

3. Environmental Governance and Legal Framework in Bosnia and Herzegovina

The environmental governance landscape in Bosnia and Herzegovina is inextricably linked to the country's intricate constitutional configuration, which mirrors its post-conflict political decentralization. This fragmented architecture distributes legislative and executive competencies across multiple layers of authority—comprising the state, two entities (the Federation of Bosnia and Herzegovina and Republika Srpska), and the Brčko District—with further devolution to cantonal governments within the Federation. While such a structure was designed to accommodate the country's complex ethno-political context, it has inadvertently produced overlapping jurisdictions, inconsistent regulatory enforcement, and a chronic lack of vertical and horizontal policy coordination.

This section critically examines the legal and institutional foundation underpinning Bosnia and Herzegovina's climate governance, with a focus on its alignment—or lack thereof—with the EU climate acquis. Through an assessment of key actors, strategic documents, and sectoral plans, it highlights the structural and operational deficiencies that hinder effective climate action. Furthermore, it underscores the marginal role of civil society and academia in shaping policy, raising concerns over democratic inclusivity in environmental decision-making.

Bosnia and Herzegovina's environmental governance is shaped by a highly complex constitutional arrangement that reflects the broader political structure of the country. Environmental policy and climate-related competencies are fragmented across multiple levels of government: the state level, two entities (the Federation of Bosnia and Herzegovina and Republika Srpska), and the Brčko District. Within the Federation, additional responsibilities are devolved to the cantonal level. This institutional fragmentation results in overlapping jurisdictions, inconsistent policy application, and limited vertical and horizontal coordination.

There is no central state-level ministry for environment or climate change. Instead, coordination functions are formally assigned to the Ministry of Foreign Trade and Economic Relations (MOFTER), which operates without full executive authority. As a result, national-level strategic coherence is weak, and the country lacks a unified legal approach to climate governance [14].

Bosnia and Herzegovina has achieved limited progress in aligning with the EU climate acquis. While certain pieces of environmental legislation have been adopted, particularly in the areas of air quality and waste management, the broader legal framework remains incomplete and non-harmonized. The country has not yet

transposed core EU directives related to climate, including the EU Climate Law, the Renewable Energy Directive, and the LULUCF Regulation [15].

Efforts toward developing a National Energy and Climate Plan (NECP) are underway but remain in preliminary stages. The adoption of Bosnia and Herzegovina's first Nationally Determined Contribution (NDC) under the Paris Agreement marked a step forward, yet its operationalization remains institutionally and financially constrained [16].

The most significant strategic documents to date include the Framework Energy Strategy 2035, the First NDC (2021–2030), and select action plans at the entity level [17].

However, their implementation is uneven and largely symbolic due to the absence of binding enforcement mechanisms and dedicated budgets [18].

Key actors at the state and entity level—such as MOFTER, entity environmental ministries, and sectoral agencies—operate with limited coordination and insufficient technical capacity [18] [19].

Civil society organizations and academia are only marginally involved in policymaking, despite the EU's emphasis on inclusive climate governance [20].

In sum, Bosnia and Herzegovina's current institutional and legal framework for climate governance reveals a system marked by complexity, fragmentation, and limited strategic coherence. Despite the formal adoption of certain environmental strategies—such as the Framework Energy Strategy 2035 and the first Nationally Determined Contribution—their implementation has been sporadic, under-resourced, and largely symbolic in nature. The absence of binding mechanisms and a clear division of responsibilities has significantly impeded the country's ability to translate international and EU climate commitments into actionable domestic policy.

Moreover, the central coordinating role assigned to MOFTER remains structurally constrained by the lack of executive authority, while the operational capacities of entity-level ministries and agencies continue to suffer from resource limitations and institutional isolation. Perhaps most notably, the exclusion of civil society and academic actors from meaningful participation in climate policy formation reflects a broader democratic deficit in the governance process. Without comprehensive reform—grounded in legal harmonization, institutional consolidation, and stakeholder inclusion—Bosnia and Herzegovina will remain ill-prepared to meet the obligations and opportunities associated with the EU's climate agenda.

4. Structural Barriers and Strategic Priorities for Climate Alignment in Bosnia and Herzegovina

4.1. Key Challenges

Bosnia and Herzegovina faces a range of systemic challenges that significantly undermine its capacity to align with the EU climate acquis and to implement climate-related obligations under Chapter 27. These challenges are structural in nature, deeply embedded in the country's constitutional and administrative framework, and compounded by persistent political and financial constraints [18] [19].

A central legal shortcoming lies in the absence of a comprehensive, state-level climate change law. While various environmental laws exist at the entity and cantonal levels, there is no unified legal instrument that establishes a coherent framework for climate mitigation, adaptation, governance, and financing. As a result, current efforts remain fragmented, largely reactive, and dependent on international donor support [19][21].

The country's administrative structure further complicates efforts toward effective climate governance. Competencies are dispersed across the state, the two entities (the Federation of Bosnia and Herzegovina and Republika Srpska), the Brčko District, and within the Federation—ten cantons with overlapping jurisdictions. This distribution leads to legal inconsistencies and frequent coordination failures [14] [22].

Although the Ministry of Foreign Trade and Economic Relations (MOFTER) is formally tasked with coordinating environmental policy at the state level, its limited mandate and lack of executive authority significantly restrict its effectiveness [14] [19].

In addition to these legal and institutional barriers, limited financial and human resources severely constrain Bosnia and Herzegovina's climate capacities. Environmental authorities are typically understaffed, underfunded, and lack the technical expertise required for EU alignment. Budgetary allocations for environmental protection remain modest, and political attention to climate issues is minimal, with environmental policy often viewed as externally imposed rather than domestically driven [23].

Addressing these persistent challenges will require more than incremental adjustments; it calls for a transformative approach to environmental governance that redefines how climate policy is conceptualized, legislated, and implemented in Bosnia and Herzegovina. The fragmented legal landscape, institutional disarray, and chronic under-resourcing reflect not only technical and administrative gaps but also a deeper systemic inertia that inhibits the development of a coherent, future-oriented climate agenda.

If Bosnia and Herzegovina is to credibly advance on its path toward EU accession, it must cultivate a unified political vision that places climate action at the heart of national policy. This entails forging cross-entity consensus, empowering state-level coordination mechanisms, and committing to long-term institutional investment. Only through such integrated and strategic efforts can the country overcome its structural limitations and build the legal, institutional, and societal resilience required to meet the obligations of Chapter 27—not as an external imposition, but as a domestic imperative for sustainable development.

4.2. Reform Priorities

In light of the identified structural challenges, a set of clearly defined reform priorities must guide Bosnia and Herzegovina's efforts to align with EU climate obligations under Chapter 27. Foremost among these is the adoption of a comprehensive, state-level climate change law that would establish a unified legal and policy framework for mitigation, adaptation, and financing [26].

Equally important is the functional empowerment of the Ministry of Foreign Trade and Economic Relations (MOFTER), including the provision of executive authority and institutional resources necessary for national coordination [24].
Institutional reform must be complemented by targeted investment in human and technical capacity at all levels of government. This includes structured support for subnational actors, enhanced mechanisms for inter-entity cooperation, and meaningful engagement with civil society and academia [19].

Finally, Bosnia and Herzegovina should make full use of EU support instruments such as IPA III, the Western Balkans Investment Framework, and the Green Agenda, not only to address infrastructure gaps but to promote long-term climate governance and administrative resilience [25].

The realization of these reform priorities represents more than a procedural obligation within the EU accession framework; it constitutes a fundamental precondition for the establishment of an effective and credible climate governance system in Bosnia and Herzegovina. Without the enactment of a comprehensive legal framework, the institutional empowerment of coordinating bodies, and strategic investment in administrative capacities, the country's alignment with Chapter 27 will remain largely aspirational. By adopting an integrated, forward-looking reform agenda—and by making strategic and sustained use of available EU instruments—Bosnia and Herzegovina can move beyond fragmented policy responses and toward a coherent, resilient, and future-proof climate policy architecture that genuinely reflects the standards and expectations of European integration.

5. Conclusion remarks

The findings presented in this study affirm that Bosnia and Herzegovina's path toward alignment with Chapter 27 remains structurally and politically constrained. While certain foundational steps have been taken—such as the adoption of strategic frameworks and participation in regional climate initiatives—these remain insufficient in the absence of systemic legal and institutional reform. The current governance architecture, marked by deep administrative fragmentation and a lack of executive coordination at the state level, undermines the country's ability to effectively plan, implement, and monitor climate policies in line with EU expectations.

A credible transformation must begin with the adoption of a comprehensive, state-level climate change law, serving as both a legal anchor and a strategic signal of political will. Equally essential is the institutional strengthening of coordinating bodies—particularly MOFTER—whose current limited mandate hampers vertical and horizontal policy coherence. Moreover, investment in technical and administrative capacity, as well as structured engagement with civil society and academic stakeholders, must form part of an integrated governance model responsive to both EU standards and domestic developmental priorities.

The European Union provides a well-defined framework of legal benchmarks, procedural mechanisms, and financial support to assist candidate countries in this transition. However, successful convergence depends on Bosnia and Herzegovina's ability to internalize these obligations—not as external pressure, but as an opportunity

to embed sustainability, legality, and resilience into its national development model. Moving from formal declarations to substantive implementation is therefore not only essential for the country's EU trajectory but also a necessary condition for long-term environmental security and social wellbeing.

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SECTION/SEKCIJA
G

Compliance of the meat supply chain and the slaughter of animals with the Halal standard

Huska Jukić, Belma Islamović and Azira Hrnjica

Faculty of Health Studies, University of Bihac

E-mail: azira.hrnjica@unbi.ba

Abstract. The application of halal standards in the food industry ensures the production of food products in accordance with Islamic dietary principles. The issue of trust in the halal status is more sensitive when choosing meat and meat products. The issue of trust in the halal status of products is the most sensitive when choosing meat and meat products. Therefore, manufacturers should standardize their products in order to be recognized on the market. To prevent contamination of halal products with non-halal ingredients, it is necessary to harmonize each phase of the supply chain with the guidelines of the standard. The guidelines contain specific requirements for each stage of the livestock farming conditions, the description of the slaughtering and processing, packaging, storage and transport procedures. This paper shows how the preservation of halal integrity is achieved, with a special emphasis on the process of animal slaughter. This is achieved by determining the critical points at which halal status can be violated, and the establishment of critical control points that will be monitored regularly. When the requirements of the halal standard are met at each stage of production, the right to a certificate is exercised, and meat and meat products contain a clearly displayed halal sign on the packaging.

1. Introduction

The demand for halal products among the growing trends in the global food market, including food in catering establishments, is particularly noteworthy. The word halal is of Arabic origin, in translation it means allowed, permitted and basically implies everything that is allowed to be consumed in the Islamic culture of nutrition. The opposite of halal is haram, which means everything that is forbidden to consume. Between these two terms is *meshbuh*, which means a product as suspicious due to its possibility of containing both *halal* and *haram*. In this case, Muslims must avoid the use of meshbuh products and seek additional status checks. The biggest problems arise precisely in the situation of suspicious, unclear products, because as such they lose their advantage when making purchase decisions with consumers looking for halal. The most sensitive area for consumers when it comes to halal food is the production of meat and meat products. Special requirements for meat are determined by legal regulations that all participants of the production chain are obliged to comply with. In order for meat to have halal status, one of the conditions is that the slaughter of animals must be carried out in accordance with Islamic regulations. The aim of this paper is to show the specific

items that must be complied with in the Halalan Toyyiban Supply Chain when it comes to meat. The paper is based on the analysis of critical points and critical control points in the process of slaughtering animals. If a particular procedure is haram, it prevents further processing of the meat or sale under the halal label.

2. Halal standard in the food supply chain

A halal standard is a document that clearly defines what is permissible (halal) and what is prohibited (haram) according to Islamic law. This Standard prescribes criteria for the implementation, certification and monitoring of the application of requirements, with the aim of ensuring compliance with Islamic rules [1]. The laws of food are explained through the Qur'an (the book of religion) and the Sunnah (the life, deeds and teachings of the Prophet Muhammad). Food is considered one of the most important factors in the interaction between different ethnic, social, and religious groups [2].

Halal Food Supply Chain (HFSC) includes all stages of the food production process, all the way to transport, reception and storage of raw materials, processing, packaging, storage of finished products and distribution [3]. Halal food manufacturers are required to apply the concept of tayyiban, which includes quality, nutritional value, hygiene and ethical practices of distribution of food products to consumers. Therefore, the modern approach in the development of the halal supply chain is also designated as the Halalan Toyyiban Supply Chain. This concept means that food is both halal and healthy to consume [4]. Also, in industrial practices, Good Manufacturing Practice (GMP) and Hazard Analysis and Critical Control Points (HACCP) standards are emphasized as additional guidelines for halal-based products throughout the supply chain process [5]. Hygiene, sanitation and food safety are the basic prerequisites for the preparation of halal food. All food safety procedures must be suitable for use in the halal food sector [6].

3. Meat production within Halalan Toyyiban Supply Chain

In order for meat to have halal status, three basic conditions must be met: The meat must come from animals that are allowed for consumption, the animals must be fed with permitted food and the slaughter of animals must be carried out in accordance with Islamic regulations. Meat without halal status is divided into two categories: meat from animals that are prohibited for consumption and meat from permitted animals that have been given components of animal origin in their diet, or slaughter has not been carried out in accordance with Islamic rules [3]. According to the standard of General Requirements for Halal Food, the following animals are considered halal: cattle, sheep, goats, camels, chickens, geese, ducks and turkeys, non-predatory wild animals such as deer, antelope, wild cattle, non-predatory birds, such as pigeons, sparrows, quails, ostriches. All types of fish with or without scales, fish eggs, prawns, and all other aquatic animals and their products. Animals that are considered non-halal are: pigs, dogs and their offspring; animals that have not been slaughtered according to Islamic

rules; dead animals; land animals with long sharp teeth or tusks used to kill prey or for self-defense such as bears, elephants, monkeys and related families, wolves, lions, tigers, panthers, cats, jackals, foxes, squirrels, marten, martens, badgers, crocodiles, alligators and others; predatory birds with sharp claws, such as hawks, falcons, eagles, vultures, crows, ravens, owls; pests and poisonous animals such as rats, centipedes, scorpions, snakes, wasps, mice and other similar animals; animals that are considered disgusting such as lizards, snails, insects and their larval stages, and other similar animals; animals (including birds and insects) that are forbidden to kill in Islam, such as woodpeckers, ants and bees; donkeys and mules; animals that have been eaten by predatory animals, animals that use their heads to hit each other, animals that fall (due to injury, blow or disease), animals that have been killed by a blow; halal animals, but which are deliberately and continuously fed harmful substances that are not suitable for their nature or are considered unclean. All toxic aquatic animals that are harmful to health are considered non-halal, unless the toxic and harmful substances have been removed [6].

In order to obtain Halal certification, the entire supply chain, from farm to fork, must be halal. The most important factors affecting the halal meat supply chain are the risks of cross-contamination during the entire process, starting from raw materials to finished products. Cross-contamination is defined as the physical transfer of harmful bacteria from one person, object or place to another. In the context of the halal principle, cross-contamination occurs when halal products come into direct contact with non-halal foods or ingredients at any stage of the supply chain [5]. In the production of high-quality meat according to the Standard, the process starts from the origin of the animals, whereby good breeding practices, pre-slaughter procedures, slaughter process, and post-slaughter procedures must be taken into account [7].

3.1 Animal husbandry under Halalan Toyyiban Supply Chain

Livestock farmers should ensure all farm conditions, including distance from pig farms in the case of mixed livestock farming, general animal welfare and vaccination regulations [8]. Each animal should be assigned a unique identification number, and all relevant data on health status and veterinary interventions should be recorded [9]. Vehicles and containers used for the transport of animals should be designed, constructed and equipped according to the specifics of the species being transported (size and weight). Special care must be taken to avoid injury to animals by using safe and smooth parts that do not have sharp protrusions. Vehicle structures should protect against adverse weather conditions and reduce the possibility of animals escaping. They should also be designed to allow thorough cleaning and disinfection, include an adequate ventilation system, food and water equipment if necessary [10]. Indoor, air quality, temperature and humidity should be maintained at a level that does not adversely affect animal health. Animal welfare is often linked to meat quality. Poorly treated and abused animals suffer from fatigue, bruising or injury, which can lead to poor quality raw meat. Injured animals tend to have higher levels of stress and develop

an increased amount of glycogen in their blood over time, which causes the meat to be dark, hard, and dry. Halal animal nutrition is based on plant ingredients without additives of animal origin, which reduces the risk of Bovine Spongiform Encephalopathy. If there is a suspicion that the animal has been fed such food or has ingested other impurities, it must be fed the correct food for as many days as necessary to purify its body [3]. Recommended poultry feed should be free of animal by-products or other waste materials.

3.2.Slaughter of large and small livestock

Slaughter sites should be exclusively for halal slaughter and must meet the requirements of the Prerequisite Programs (PrPs), defined by Codex alimentarius – CAC/RCP 1, ISO 22 000 or ISO/TS 22 002 (all parts). The physical conditions in slaughtering places must meet national legal requirements. The general requirements for halal slaughter include that the animal must be halal (allowed), healthy, confirmed by a veterinary examination and must be alive at the time of slaughter [3]. *Zabiha* or *Dhabiha* is a term that in Islamic legislation refers to meat that has been slaughtered in the halal manner. The word *Dhabh* means the process by which an animal is prepared for consumption [11].

The person performing the slaughter must be an adult Muslim who is mentally healthy and fully understands the basic rules and conditions related to halal slaughter. The person carrying out the slaughter must be professional and experienced in relation to the slaughter process, as well as meet the requirements related to health, general hygiene and food safety rules. The slaughter procedure is carried out in such a way that the animal is restrained and placed on its left side, facing the Qibla (in the direction of Mecca). Care should be taken to reduce the suffering of the animal while it is being placed, and not to keep it in this position for too long. The slaughterman begins the process by saying the tesmiyya, i.e. the ritual words "*Bismillahi Allahu ekber*" ("*In the name of God, God is the greatest!*").

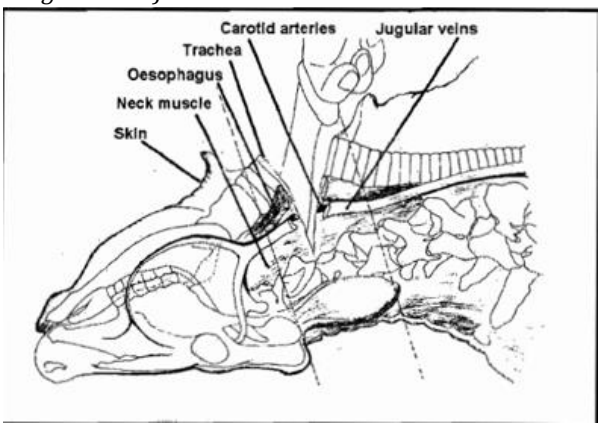


Figure 1. Method of slaughtering cattle (MS 1500:2009)

Figure 1 shows the process of halal slaughter. The act of slaughter begins with an incision in the neck just below the glottis (Adam's apple), that is, after the glottis in animals with a long neck. In order for the slaughter to be completely successful, the trachea (Arabic *halqum*), the esophagus (Arabic *mari*) and both carotid arteries and jugular veins (Arabic *wadajain*) are cut (Figure 1)[6, 12]. Carotid arteries and jugular veins deliver oxygenated blood to the brain, and by cutting them, the animal dies due to lack of circulating blood and consequent cerebral anoxia [13]. The instrument (knife) used for slaughter must be sharp, made of stainless steel. Cutting must be done with a blade and not with weight or pressure, nor can bones, nails or teeth be used as tools for slaughter. The incision must be on the front above the chest, not on the side of the neck or back. Before any part of the carcass is cut, peeling of the skin, scalding or removal of feathers in poultry, complete death of the animal must be ensured [6, 12]. The whole process should not take more than 40 seconds, and the animal should not be injured due to improper position or high pressure [3]. According to the UAE.S. 993:2022 standard, the amount of blood during bleeding must be monitored and if a smaller amount of blood than normal is observed due to cardiac arrest, the carcass is treated as non-halal.

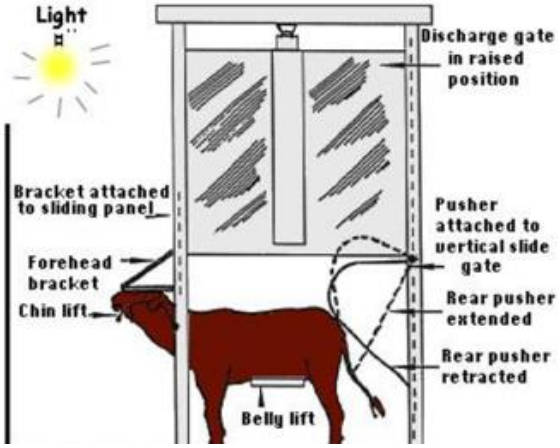


Figure 2. Standing box for restraining livestock

Stunning implies the procedure of disabling animals before slaughter (Malaysian Halal Protocol, 2011). All methods of stunning and loss of consciousness are prohibited. However, when the use of an electric shock becomes necessary to calm or prevent violent behavior of the animal, it should be aligned with the permissible period and values of the electric current. When stunning is permitted, the following conditions must be met: the animals must remain alive after stunning and before they are slaughtered. If death is determined before slaughter, they are considered fatally struck animals. It is forbidden to incapacitate an animal with a slaughter tool, cutter, hammer

or in other ways [6]. If a stunning procedure is performed, slaughter must be performed immediately after loss of consciousness, and the animal must not regain consciousness before death caused by slaughter occurs. It is recommended that halal slaughterhouses be equipped with specialized restraint devices that allow the animal to be safely kept in the correct slaughter position without the need for stunning.

Such devices, known as "halal slaughter boxes", are designed to immobilize the animal to prevent its injury and allow for the proper act of slaughter. The head and neck of the animal remain outside the box, fixed with holders, to enable precise cutting of the cervical vessels in accordance with halal standards (Figure 2).

At least two surveillance cameras must be installed on the production lines near the area where the animals lose consciousness (each with an independent system). It is necessary to record the process to determine whether standard stunning procedures cause the death of the animal. Also, there must be adequate storage capacity for film recordings (at least 90 days) that are available on demand (UAE.S 993:2022, general guidelines and Appendix A).

2.2. Slaughter of poultry

In industrial slaughterhouses, poultry slaughter lines are usually automated, and there are also automatic stunning systems. In manual slaughter, the person slaughtering must properly tighten the head of the poultry and cut the neck with a sharp knife (Figure 3).

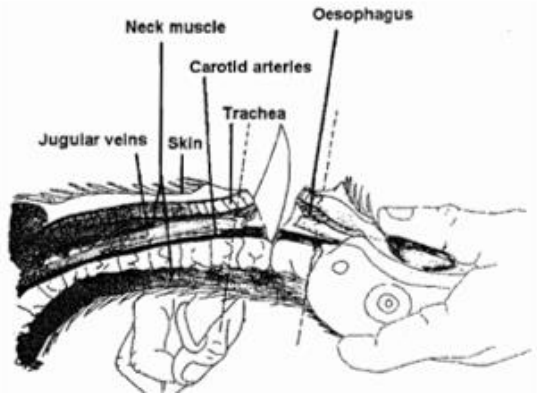


Figure 3. Method of slaughtering poultry (MS 1500:2009)

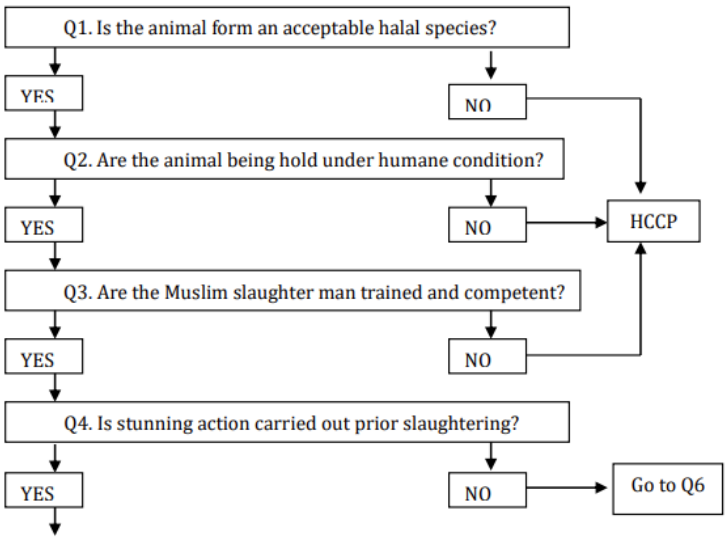
In the case of automated slaughter, the operator of the mechanical knife must be a Muslim and say "Bismillahi Allahu akbar" when starting the knife. This procedure must be repeated for each individual act of slaughter, and the use of automatic devices for pronouncing this expression is not permitted. The knife used must be sharp, made of stainless steel and suitable for cleaning. If the mechanical knife fails to properly slaughter an individual, manual slaughter must be carried out. The bleeding period must last at least 180 seconds [3].

2.3. Slaughter of other animals

No slaughter is required for fish. They need to be taken out of the water while they are still alive so that death occurs outside the water. A fish is not halal if it is found dead and floating at the time of fishing. Poisonous and sick fish are not halal. Other animals, which are hunted by a Muslim person, are considered halal if a tesmiyya is pronounced before killing and the animal is hit by the sharp edge of the weapon [6].

4. Haram Analysis Critical Control Points

In order to establish a system of control and monitoring of production processes and confirm the halal status of products, it is necessary to implement the HrACCP system (Haram Analysis Critical Control Points). HrACCP includes the analysis of the entire production chain through all stages, from primary agricultural production, through processing and packaging, to the distribution of products to the end user. The aim of this analysis is to identify potential points at each stage that could lead to non-compliance with halal standards. Therefore, it is advisable to perform haram analysis to identify haram critical control points. This term is modeled on HACCP (Hazard Analysis Critical Control Points), a system that deals with the identification, assessment and control of food safety hazards. The methodology and approach of both systems are identical, with the difference that HACCP identifies food safety hazards, while HrACCP analyzes critical points that could lead to haram [3, 14]. The principle of determining haram critical control points (HrCCPs) using a tree, based on the standard MS 1500:2009 Halal food – Production, preparation, handling and storage, shown in Figure 4.



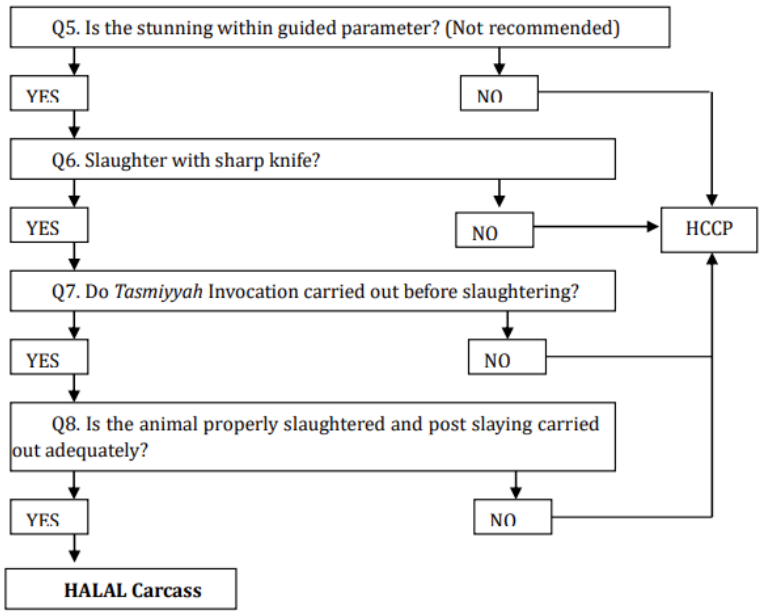


Figure 1. Halal Critical Control Point Decision Tree for Slaughtering animal (Ramalingam et al, 2012)

This standard requires compliance with MS 1480 – HACCP or MS 1514 – Good Manufacturing Practice. On Figure 4 is shown the HACCP concept is adapted to halal standards to identify and eliminate possible impurities or haram, with zero tolerance for non-compliance with Islamic food laws. The process involves monitoring critical control points for haram and taking corrective action in case of deviation [15].

3.1. Halal control points in meat industry

Halal control points (HCPs) can be determined for each stage of the process. HCP for the meat processing ish shown on Figure 5 [2].

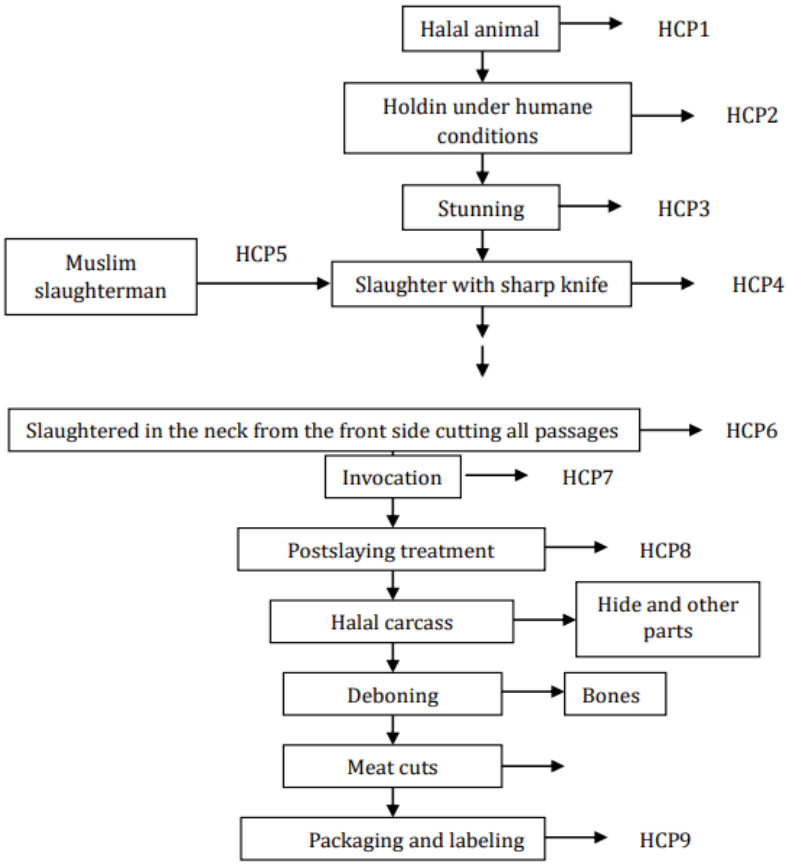


Figure 2. Halal control points in meat processing (Riaz and Chaudry, 2004)

HCP1 means that the animal must belong to species that are halal (allowed) for consumption in Islam. HCP2 refers to the treatment of animals. Animals must be treated so that they are not stressed or excited before slaughter. HCP3 refers to stunning. It is recommended that animals be slaughtered without stunning, but some non-lethal stunning methods can be used. HCP4 refers to the sharpness of the knife. The knife must be sharp so that the animal does not feel pain when cutting. HCP5 refers to the person who performs the slaughter and requires that the person performing the slaughter must be of legal age, mentally capable and familiar with the slaughter process. HCP6 – The act of slaughter. Rapid cutting of the neck, trachea, esophagus, carotids, jugular veins, without reaching the bone in the neck. HCP7 refers to the obligatory pronunciation of God's name while cutting the neck. HCP8 refers to the post-slaughter procedure. It is not allowed to cut off parts such as ears, horns or legs before the animal is completely dead. When the bleeding stops, the heart stops and the animal dies, further processing of the carcass can be started. HCP9 - packaging and labelling. The meat is packed in

clean packages and boxes. Appropriate markings with a halal sign are placed on the packages [2].

5.Certification procedure and halal sign

In order to obtain a halal certificate, it is necessary to implement the mentioned HrACCP system. HrACCP is based on several principles: haram analysis (a flow chart is used for the identification and analysis of prohibited substances), determination of critical control points where halal status can be lost, i.e. haram occurs, and establishment of monitoring procedures, establishment of procedures for verification and establishment of a documentation system. The process of certification of halal products is carried out by organizations authorized by the Islamic religious community.

The Halal Quality Certification Agency conducts the certification process based on a uniform procedure [16]. The applicant (interested organization) submits a request to the Agency and submits the necessary documentation. The Agency reviews the submitted documents, and if all requirements are met, sends the applicant an offer for halal certification. After the applicant accepts the offer, the Agency and the applicant conclude a contract for a period of three years. The halal certificate is issued for a period of one year, and in the remaining two years of the contract, the Agency conducts announced or unannounced supervisory audits and laboratory analyzes to confirm that the organization still meets all the requirements of the Standard (Halal Quality Certification Agency, 2024b). Laboratory analyzes are divided into mandatory and recommended. Mandatory analyzes include checking the presence of the following ingredients: pork DNA, protein and pork fats/lipids, alcohol (ethanol), genetically modified (GM) raw materials and pork proteins and fats in animal feed and poultry feed. Recommended analyses include microbiological, chemical and physical analyses. Recommended analyses become mandatory if, during an audit or other procedures, it is determined that the product does not meet health regulations. Recertification is carried out at the end of the certification cycle, which lasts three years, with the signing of a new contract. The certification audit is performed in organizations whose certificate has not been suspended or withdrawn. An organization that does not renew the certificate loses the right to use it and display the halal sign [3].

The Agency has developed a trademark that represents the Agency's logo and is used to designate halal products (Figure 6). The halal label is registered with the World Intellectual Property Organization (WIPO), which prohibits its use without the Agency's permission. The halal label can be used by manufacturers who have successfully applied the Standard and by sellers and distributors who have received written approval from the Agency. The use of the Halal sign without the prior written approval of the Agency is strictly prohibited and legally punishable (Halal Quality Certification Agency, 2024c).

Figure 3. Halal mark of the Agency for Halal Quality Certification (Certification Agency Halal quality, 2024)

3. Conclusion

Among consumers who consume halal, the most prevalent demand is for halal meat and meat products. There is a lack of knowledge about what the Halal standard entails. On the other hand, there is a lack of trust in halal status on the part of consumers. For this reason, it is very important to understand the importance of implementing the HrACCP system (Haram Analysis Critical Control Points) and establishing critical control points in the flow diagram of the entire process where haram substances may appear or the status of halal may be lost through a certain improper procedure. First of all, it is important that the meat comes from a halal animal, which is farming in humane and acceptable conditions. The animal should be killed in a halal way, which often involves manual slaughter with a sharp knife according to a well-known procedure for a particular animal, all in order to reduce the suffering of the animal. When slaughtering, it is necessary that the person performing this procedure be a Muslim and that he pronounces the *Tasmiyyah*. It is important to respect the period of bleeding and not to start processing the carcass until the animal is completely dead. In addition to this, meat and meat products should meet food safety requirements: microbiological, chemical and physical characteristics must not endanger the health and life of consumers. Finally, the use of the halal label on meat and meat products is allowed to producers only if they have implemented the Halal standard in their company or to distributors who have received the written approval of the Agency. The use of the halal sign without meeting these conditions is illegal and punishable by law.

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Causes of Soil Degradation and Protection Measures in Bosnia and Herzegovina

Mirsad Ičanović[1*], Mihajlo Marković[2] and Vildana Jogić

[1]University of Bihać, Biotechnical Faculty, Bihac Bosnia and Herzegovina
[2]University of Banja Luka, Faculty of Agriculture Banja Luka, Bosnia and Herzegovina
[3]University of Bihać, Technical Faculty, Bihać Bosnia and Herzegovina

E-mail: icanovicmirsad@yahoo.com

Abstract. Soil/land is one of the most important natural resources of every country, including Bosnia and Herzegovina. Its primary function is the production of food and raw materials in the fields of agriculture and forestry, as well as various technical functions. Bosnia and Herzegovina is significantly affected by numerous soil degradation processes, which are more or less pronounced in different areas. This paper presents the main causes of soil damage in Bosnia and Herzegovina caused by surface exploitation of various raw materials, construction of settlements on arable land, development of water erosion and landslides, and the presence of residual landmines. The consequences of soil damage in Bosnia and Herzegovina are classified into four different categories: soil contamination, soil pollution, soil degradation, and soil destruction. Additionally, this paper highlights several measures taken to protect and rehabilitate soil in Bosnia and Herzegovina. These include soil reclamation and rehabilitation, balancing ecological and technical soil functions, changes in land use on slopes, soil monitoring, establishing a soil information system, demining processes, and the crucial need for developing a special Soil Protection Law.

1. Introduction

Soil is one of the basic and most important natural resources. One of the basic soil functions is the production of food and raw materials, but the soil is also used for other purposes outside the sphere of agricultural production, for the construction of residential buildings, roads, surface mines, mineral raw materials, etc. The limited area of arable agricultural land imposes the obligation of proper and rational use of space for both agricultural and non-agricultural purposes. From the above mentioned, it is important to consider how these potentially conflicting tendencies can be reconciled, and land can be assigned an optimal role in an ecological or technical sense. Absolute soil protection measures currently do not exist, and the land is exploited in a traditional

way, very often without adopted spatial plans or compliance with legal frameworks in the sphere of land protection. However, it is possible to apply such measures and care, which can reduce the loss of quality soil. In doing so, it is possible to reconcile the relationships between many different pressures on soil resources. Bosnia and Herzegovina is under the intense influence of numerous soil degradation processes, which are particularly pronounced in certain areas. The reasons for this are numerous and include: society's attitude towards soil, meaning the inhabitants do not understand the importance of soil and there are no responsible policies for its protection. Also, the civil war, which harrowed the geographical area, left numerous consequences on the soil.

2. Materials and work methods

Lands in Bosnia and Herzegovina, as well as in the entire region of Southeast Europe, represent an extremely vulnerable and sensitive resource that should be treated with special care. Land degradation has not been seriously investigated at the level of BiH, but also of the entire region, so it is very difficult to objectively assess the situation. Absence of a system of sustainable land management and systematic quality monitoring of land results in its destruction and disappearance.

3. Results of both work and discussion

3.1 Relief, climate and soil of Bosnia and Herzegovina

The total area of Bosnia and Herzegovina is 5,112,900 ha (51,112 km2), 49.4% is considered agricultural, 45.6% forest, and the area without vegetation and soil occupies about 5%. 568,860 ha, i.e. 11.13% of agricultural land, are lost to soils affected by excess water – hydromorphic waste, while automorphic soils account for the rest. Due to the war events in Bosnia and Herzegovina, the number of inhabitants diminished from 4,300,000 in 1991 to 3,300,000 in 2002, according to data acquired from 2002. If we consider the number of inhabitants of Bosnia and Herzegovina, we arrive at the data that per inhabitant there is 0.59 ha of agricultural land, that is, 0.36 ha of arable land.

When it comes to relief, it is very different, both in terms of appearance and age and the way it was created. Most of the relief of the country consists of mountains of different heights. Bosnia and Herzegovina consists of two geographical and historical entities: the larger Bosnian part in the north (about 42,000 km2) and the smaller Herzegovina part in the south.

The amount of climatic precipitation differs in certain parts of the country. The average amount of precipitation is 1,200 mm. The individual zones range from 800 mm in the northern zone to 2,000 mm in the southern zone. Due to its position, Bosnia and Herzegovina is viewed both as a Balkan, but also as a Mediterranean country, as well. The largest part of Bosnia and Herzegovina's territory belongs to the southernmost

branches of the northern temperate zone and the northernmost parts of the subtropical zone.

The boundary between these zones is drawn based on the radiation balance and the general pattern of air circulation, which is characteristic of both thermal zones. In addition, the area of Bosnia and Herzegovina sectorally belongs to the inflow of the winter western cyclone and the summer Azores anticyclone with increased tropical influences.

Table 1. General situation of agrohydrological balance in BIH (mm).

Hydrological parameter	BIH average	South area	Central area	North area
Precipitation (P)	1.200,00	2.000,00	1.000,00	800,00
Potential ET-PET	725,00	900,00	650,00	700,00
Real ET-RET	600,00	600,00	600,00	600,00
Water Deficit-D	125,00	300,00	50,00	100,00
Water Surplus-S	600,00	1.400,00	400,00	200,00
Drought coefficient-P/PET	1,65	2,22	1,54	1,14
Outflow coefficient-S/P	0,50	0,70	0,40	0,20

3.2. Causes and consequences of soil damage in Bosnia and Herzegovina

3.2.1. Causes of soil damage

The causes of soil damage in Bosnia and Herzegovina can be of different origins and are reflected in several segments of social activity.

The first way of damaging the land is certainly the exploitation of various raw materials. It is mainly about surface exploitation. There are many deposits of various ores in Bosnia and Herzegovina, and very deep and wide craters are formed during exploitation. Surface mining created about 20,000 ha of such degraded areas.

Another cause of damage is certainly the abandonment of agricultural soil/land. Such damage to the soil is the result of war operations, which resulted in the emigration of the population from some areas, which is why they concentrated in other zones. Such migration mainly refers to the movement of residents from villages. For the possibility of their relocation to new areas, it was necessary to build new settlements. In these actions, the construction of new houses mostly took place on the best soil. The bigger problem is that there are no large areas of good soil in Bosnia and Herzegovina (only about 14%). It was this kind of pressure on this land fund that caused the loss of large areas of the best soil. We should not forget the disposal of various types of waste, water accumulation, the construction of infrastructure (roads, railways, industry) resulting in irretrievable loss of land, the development of water erosion and landslides, etc.

The problem of water erosion is currently present, but also an occurrence in earlier periods in this area. As a result of unwise planning, or lack thereof, and elemental deforestation on strongly inclined surfaces, very strong gullies, and consequently landslides, appeared caused by erosion. The high slope of the area favors water erosion, especially when the slopes are cultivated for the cultivation of crops. The increased intensity of water erosion is caused by the undisciplined cutting of the forest cover, which has the character of the so-called total cutting. During the war, forest areas were cut very intensively to feed the needs of the army, which were the priority. In the post-war period the process of the forest cutting became significantly more intensive and continued as such. During the war, large areas of the country were contaminated by mines, and it is estimated that around 420,000 ha of the territory of Bosnia and Herzegovina is covered with mines, namely that there are more than a million mines in 30,000 minefields. With such pressure from mines (besides bringing great dangers to the population) come significant economic consequences. Those areas can no longer be used for agriculture.

Some of the consequences of soil damage are certainly: soil infection, soil pollution, soil degradation and soil destruction. Soil infection is a special form of soil pollution, which is reflected in the possibility of soil infection through domestic or wild animals and breeds of dogs and cats. This is primarily reflected in parks where pets and people, and primarily children, move. By leaving their secretions, dogs or cats potentially spread an infection that can easily be transmitted to humans. While soil pollution is caused by the deposition of various pollutants on and in the soil, in different aggregate states.

Figure 1. The sources of soil contamination

Figure 2. The sources of soil contamination

Soil degradation is a global problem with consequences such as questionable food security, climate change, vulnerability to drought, reduced drinking water quality, flood risk management, reduced agricultural resistance to new diseases, reduced biodiversity, etc.

Figure 3. The soil structure damages

Figure 4. The soil structure damages

Table 2. The most frequent loss of agricultural land in BIH (estimation)

Cause of soil destruction	*Soil losses (per year)*	
	ha	*%*
- surface mining	900,00	30,00
- disposals	300,00	10,00
- settlements	600,00	20,00
- water accumulations	300,00	10,00
- roads	300,00	10,00
- industry	300,00	10,00
- erosion, sliding, etc.	300,00	10,00
TOTAL	3.000,0 0	100,00

3.2.2 *Soil protection measures*

Soil protection includes preservation of soil health and function, prevention of damage, monitoring of soil conditions and changes in soil quality, and remediation and restoration of damaged soils. The soil is adversely affected by improper use of chemical agents in agriculture, soil erosion, reduction of forests, demographic expansion and urbanization, industry, mining, and desertification. Pollution, i.e. soil damage, is considered a harmful impact on the environment. Some of the measures are definitely recultivation of the fly ash disposal site. This measure must be carried out in places where there is reclaimed with soil cover. Agricultural production exhausts the vitality of the land, long-term cultivation and cultivation of agricultural crops affect its quality, and the excessive use and use of harmful chemicals is especially harmful, which is reflected in the food we eat and the water we drink.

Apart from partial research, in Bosnia and Herzegovina there is a lack of a developed soil quality monitoring system that would show the situation with the residues of various chemicals, where only a few farmers perform the necessary fertility control and analyzes for harmful organic and mineral ingredients. Soil quality control data are useful for farmers in finding answers to questions about the correct use of organic and mineral fertilizers for the nutrition of cultivated plants, planning of

cultivation, and application of chemicals in protection against pests. Also, such research and monitoring can indicate land degradation processes due to the excessive use of certain chemicals in agriculture, as well as secondary sources of pollution from industry, traffic, etc. Plant protection agents, which are often called pesticides, are used to protect agricultural crops from harmful organisms, diseases or other plants, for the sake of greater efficiency of food production in conventional and ecological agriculture. Pesticides can be of chemical or non-chemical origin (e.g. microorganisms), and their residues in food and animal feed can be harmful to consumers. Special attention should be paid to legislative measures, which imply the drafting of a special law, i.e. of the Law on Soil Protection. Through the agricultural development strategy, create a program for the protection of hilly and mountainous areas from water erosion by introducing soil and water conservation measures along with sustainable agricultural development. Activate the mechanism of assessment of potential and active processes of soil erosion in BiH, implementation of significant and experimental watersheds according to European experiences for monitoring processes of soil erosion and sedimentation in relation to land use. It is necessary to create a NAP (National Action Plan) according to UNCCD instructions and obligations, and revitalization of karst sub-Mediterranean areas (limestones and dolomites) - areas that cover more than one third of the national territory that has been drastically eroded and decertified. Demining the territory of BiH is an extremely important and urgent task for many people, in regard to social, economic, ecological and security reasons. Flood protection and drainage of lowland areas in river valleys and karst fields (which covers a total of about 400,000 ha).

4. Conclusion

Through the chapters of this paper, the main problems of soil damage in Bosnia and Herzegovina are presented. They are reflected in four different types of soil damage, namely: infection, contamination, degradation and destruction. Annual losses, only due to soil destruction processes, amount to about 3000 ha. Processes that are problematic today in Bosnia and Herzegovina are particularly important, namely: surface exploitation of various raw materials, construction of settlements on arable land, development of water erosion and landslides, and the presence of mines. In order to practice soil protection in the countries of this region, several different measures have been proposed. These include cooperation in the domain of soil recultivation and remediation, changing the way soil is used on slopes, and the important need to draft a special law, namely the Law on Soil Protection. Given that a permanent increase in soil consumption by non-agricultural consumers has been established, it is necessary to do the following:

- To form a special group that will take care of land treatment through individual laws.

- The Law on Mining should specify the time limits and more detailed obligations of the user, in which period the reclamation must be carried out.
- In the Spatial Planning Act, it is foreseen that expert bodies, during the construction of settlements, factories, roads, etc. include agricultural experts - soil specialists for providing the location of future facilities.
- Strive to create land use value maps in all municipalities, at a scale of at least 1:10,000.
- As part of certain institutions that deal with soil studies, form departments for recultivation and land reclamation.
- Within individual municipalities, keep a special report on land losses during the year by various consumers.

The main problems for soils in the EU are irreversible losses due to increasing soil sealing and soil erosion, and continuing deterioration due to local contamination and diffuse contamination (acidification and heavy metals). The incremental loss and deterioration of Europe's soil resource will continue, and will probably increase as a result of climate change, land-use changes and other human activities. Strategies for soil protection, and systems for monitoring of soil, are not adequately developed at European or national level, as compared with air and water for which monitoring, assessment and policy frameworks are already in place. A policy framework is

needed which recognises the environmental importance of soil, takes account of

problems arising from the competition among its concurrent uses (ecological and socioeconomical),

and is aimed at maintaining its multiple functions.

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Evolution of quality approaches development in accordance with industrial development

Senada Pobrić[1] and Emir Bajramović[,2]

[1] University Džemal Bijedić, Faculty of Mechanical Engineering, Mostar, Bosnia and Herzegovina
[2] University of Bihać, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina

E-mail: emir.bajramovic@unbi.ba

Abstract: History has shown that the concept of quality has a dynamic character. It changed continuously depending on the development of societal needs, as well as the constant development of science and technology. Therefore, throughout history, there have been needs for changes in quality approaches, in order to achieve a level of product quality that will satisfy customer requirements. Each new approach is an improved version of the previous one, that is, the new approach is an upgrade on the previous ones. Observing the evolution of quality approaches development, the following approaches can be observed: Quality Control (QC), Quality Assurance (QA), Total Quality Management (TQM) and Total Quality Management - integrated approach. Support for the mentioned quality approaches was made possible by technological achievements that marked certain industrial revolutions. In addition to the fact that the industry dictated and continues to dictate the way of life characteristic of a certain period, it also dictated ways of approaching quality. The paper will present the specifics of certain industrial revolutions and their impact on the development of different quality approaches. The specifics of each quality approach will be described in the paper.

1. Introduction

The end of the last century is characterized by the beginning of the globalization process and the creation of a single world market, which set certain preconditions for the survival and growth of organizations in the market. In order to adapt to these conditions, organizations need to invest in: knowledge, new technologies and innovations, as the three most important factors for success. It has been shown that successful organizations are those that are guided by quality, that is, guided by the satisfaction achieved in the way they work, the level of services they provide and the products they deliver. Quality has become a basic tool in the fight against competition. It can be seen as a challenge and a space for creative activities, which decisively affect the business success of every organization. Organizations should strive for the same

goal, which is to meet the demands and expectations of customers, and even exceed their expectations. Quality is what the customer wants, needs and can pay for. The evolution of social needs and scientific and technological development initiated the dynamics of quality. The approach to quality has changed continuously in accordance with the changes that have occurred throughout history in the social and industrial world. The growth of customer demands has been accompanied by the continuous development of technologies. It was necessary to find ways to respond to the increasing demands of customers. It can be said that any change in the approach to quality is actually a civilizational response to all the challenges brought to us by industrial society throughout history. Over time, various approaches to quality can be observed, which differed in terms of orientation, objectives, used methods, etc.

2. Historical development of quality

Due to changes in society, economy, technology and science, approaches to quality have also changed over time. The approach to quality refers to the way in which quality is approached in terms of managing this phenomenon. The first knowledge of the term "quality" has existed since ancient times. At that time, craftsmen created goods of a certain quality, and buyers were the ones who assessed the quality of the goods. In the period from the 13th to the 19th century, there was an inspection that controlled the products of craftsmen, organized into guilds, using inspection signs that were proof of product quality, [1]. However, the modern history of quality development begins in parallel with the development of technologies, means of work, technical requirements of products, or with the emergence of industrial revolutions, [2].

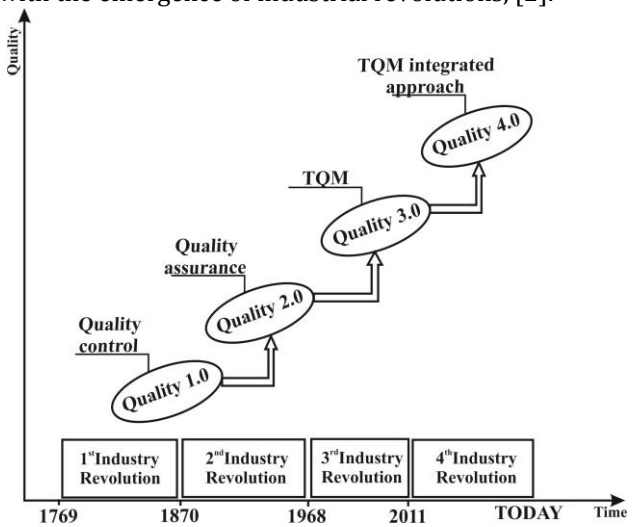

Figure 1. Industry development and stages of quality evolution.

Observing the historical development of industry and the phases of quality evolution, one can see the significant influence of industrial revolutions on the development of various approaches to quality, (Figure 1). In addition to dictating and dictating a way of life appropriate for a certain period, industry also dictated ways of approaching quality, with the evolution of quality always lagging behind the evolution of industry.

With the advent of the First Industrial Revolution, at the end of the 18th century, the production of more complex products and processes came about, which later required the introduction of some approach to quality. The change that followed was only one small step. The final products were controlled by the factory owner himself. In the First Industrial Revolution, Quality 1.0 was present, which included inspection for the elimination of defects and quality control [7]. With the further development of industry, the complexity of products and production processes grew, which forced companies to devote themselves more seriously to quality. It can be said that the real quality revolution began with the first half of the 20th century, during the Second Industrial Revolution, with the introduction of statistical quality control and standardization. The Second Industrial Revolution enabled the transformation of quality into Quality 2.0, which was characterized by quality assurance. At the end of the 20th century, with the Third Industrial Revolution, global competition increased. This influenced companies to devote themselves to improving quality and its control. The result of the Third Industrial Revolution is Quality 3.0, which included quality improvement with the help of the TQM model, which was created to help organizations manage and improve quality in all business activities. Total Quality Management (TQM) improved the understanding and use of quality standards to a higher level, emphasizing concepts such as organizational learning and participatory management, [3].

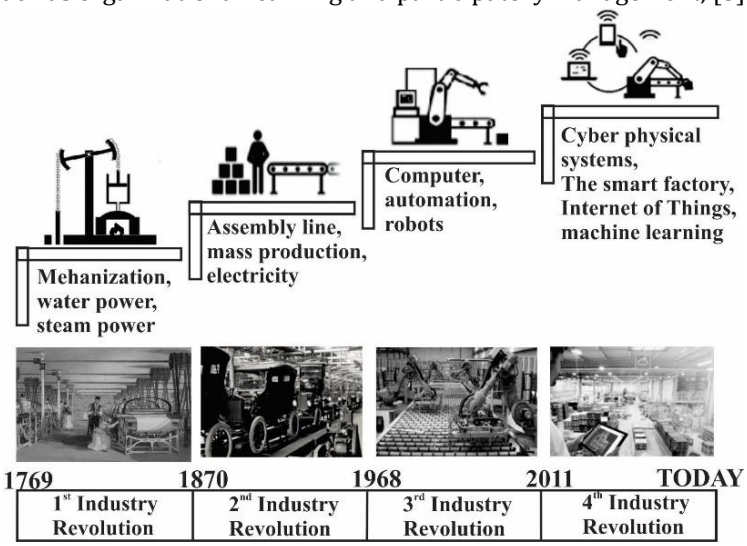

Figure 2. The development path of the industry.

Quality management began to expand drastically and change significantly. At the beginning of the 21st century, namely with the Fourth Industrial Revolution, quality professionals were faced with a significant challenge in finding an approach to quality that would match the current industrial development. With the Fourth Industrial Revolution, a new concept of quality management, Quality 4.0, emerged, which helps to improve the speed of decision-making, predict changes, and adapt to new situations.

Each industrial revolution brings with it certain improvements compared to the previous one, all to facilitate the production process, faster, better quality, and safer work. From the transition from manual work to machine work, the introduction of electrification and assembly lines, and the emergence of computers and robots, to the current application of cyber-physical systems, the development path of industry has flowed through four industrial revolutions (Figure 2).

Alongside the development of industry, quality also followed its path of evolution—a process of adapting quality requirements in line with scientific and technological advancements. The development path of quality is reflected in various approaches to quality: quality control, quality assurance, total quality management (TQM), and an integrated approach to total quality management (Figure 3), [4].

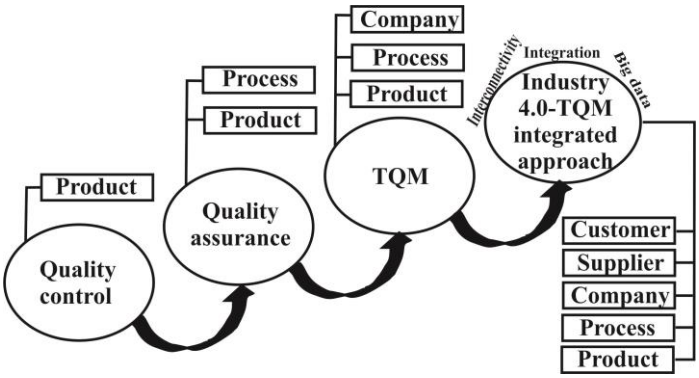

Figure 3. Phases of quality evolution and their scope, [4].

Each subsequent approach is an upgrade to the previous one with modification and adaptation to new production circumstances, brought about by the industrial revolution. Technology has always had an important impact on the quality of an organization and its performance. This impact is particularly pronounced today, in the era of the Fourth Industrial Revolution, going through the process of digital transformation, [5]. The specificities of individual industrial revolutions and their impact on the specificities of individual quality approaches will be described in the following chapters.

2.1 The First Industrial Revolution and Quality 1.0

The First Industrial Revolution began in the second half of the 18th century with the emergence of revolutionary changes in the previous mode of production thanks to a series of technological innovations. Among the most important innovations can be mentioned: the appearance of the first steam engine (1769), the appearance of the first mechanical loom (1784), the transition from manual production to mechanical, factory work system. The way of working changed, work was done faster, while the transport of goods became more frequent [6]. The machines were powered by steam, and coal was the main source of energy. The volume of production was a priority over quality. With the emergence of large factory systems, it was necessary to control the quality of products. During that period, the factory owner performed product control at the end of the process. Product quality depended on the skills and knowledge of factory workers, with the constant presence of quality control. This period of quality evolution represents the first phase of quality development, designated as Quality 1.0 with a concept called quality control, [8]. It was a product-oriented approach, and the goal was to identify product nonconformities before delivery to customers. In this way, it was possible to prevent the delivery of defective products to customers. The disadvantage of such an approach to quality is reflected in the high costs due to errors during the production process and the generation of waste. No efforts were made to reduce costs, eliminate waste, or prevent nonconformities.

2.2. The Second Industrial Revolution and Quality 2.0

The Second Industrial Revolution covers the period from the end of the 19th century to the middle of the 20th century. What is characteristic of it is the construction of railway and telegraph networks and the application of electricity. This enabled faster transport of people and ideas. The beginning of the Second Industrial Revolution is associated with the appearance of the first production line (1870), which brought major changes to the industry. Electrification contributed to the development of modern production lines in factories, which resulted in increased productivity and economic growth. The use of automated machines and assembly lines ensured mass production. Oil became the most important source of energy. Innovations within the Second Industrial Revolution were of a more significant intensity compared to the previous revolution and had an impact on the further development of quality. Especially at the beginning of the 20th century, when it can be said that the real quality revolution began. Due to increasing automation and modern production lines, with constant product control, it was necessary to change something in terms of quality. Control services were formed that carried out quality control, which represented the first step of a professional approach to quality. It was not enough just to control the product, but also to ensure the achieved level of quality. The focus that was until then on the product was extended to processes. Quality monitoring in that period took place according to a concept called quality assurance. The characteristic of that concept is a process-oriented approach which, with the help of standardized and maintained production processes, ensures the

achievement of the same level of product quality, [8]. The main purpose was to deliver products without defects with an emphasis on maintaining production processes. Minimum acceptable quality is set as a standard. The focus was still on maximizing productivity, [6]. That period of quality evolution represents the second phase of quality development, marked as Quality 2.0, which was oriented not only to products but also to processes. For the first time, a process approach appears in quality management. The goal was to ensure the achievement of the same level of quality by standardizing processes. One of the quality gurus who made this period official was Walter A. Shewhart, who in 1924. introduced the first control chart, a statistical method, in production quality control. Most control charts that are used today are based on Shewhart's control chart. In addition to developing statistical process control (SQC-Statistical Quality Control), he is also the originator of the well-known PDCA cycle (Plan-Do-Check-Act) of continuous quality improvement. In 1939., Shewhart proposed a quality improvement method applicable to all areas and levels of an organization's life and work, which was named the "Shewhart Improvement Cycle", [9].

2.3. The third industrial revolution and Quality 3.0

The third industrial revolution covers the period from the middle of the 20th century to the beginning of the 21st century. This is a period characterized by the beginning of digitalization, or the beginnings of the development of information technology and computerization. The beginnings are associated with the appearance of the first industrial computer (programmable logic controller, 1968.) which served as an aid in controlling production processes, while in the 1980. the first personal computers were introduced into offices. Unlike the Second industrial revolution, where the emphasis was on mass production, the emphasis in Third industrial revolution is on adapting products to customers according to their needs and desires. The main focus is on customer requirements. Due to increasing competition in the market, companies are putting the needs and desires of customers at the forefront. Computers, mobile phones and fax machines are becoming a part of people's everyday lives. The introduction of automation and robotics in production is also something that marked Third industrial revolution. The use of the internet has become an almost indispensable factor in every industry. This raised industrial productivity to an even higher level, [10]. From the period of Third industrial revolution until today, information technologies are considered the most important carrier of social progress. Various systems are being developed that improve business operations by reducing production time, eliminating non-conformities, and reducing production costs, which has been a major advance for production. All the challenges brought by the third industrial revolution have accelerated further development in quality management. The third phase, known as Quality 3.0, is associated with this period of quality evolution, which is oriented towards the entire organization and carries a completely new quality concept called Total Quality Management (TQM). The comprehensiveness of the approach has been expanded, in addition to products and processes, to the entire organization. The quality

approach is oriented towards the entire business of the organization. The goal is to ensure that all activities within the organization are implemented with quality and continuously improved, in order to meet customer requirements and expectations. Quality has become a business imperative, something that is indispensable in business, in which leadership plays a major role. Leadership should enable the unity and direction of the organization in achieving the stated goal. Achieving the required quality requires the participation of all departments in the organization. The emphasis is on continuous quality improvement and customer satisfaction. During that period, in addition to TQM, the most common management system, other management systems were also implemented, the most famous of which are: Six Sigma, Lean Management, etc., whose roots are in the ideas of many quality gurus. After Shewhart, the person most deserving of credit for the further development of statistical quality control is W. Edwards Deming, who was a great supporter of Shewhart's SQC (Statistical Quality Control) methods. He worked on Shewhart's improvement cycle and over time upgraded it, so that in 1950. he introduced a new version, the so-called PDCA cycle, today known as the Deming cycle [11]. In addition to Deming, there are also Joseph Juran, Armand Feigenbaum, Philip Crosby and many other quality gurus who each contributed in their own way to quality management and thus colored the observed period with quality. Their ideas have significantly shaped the development of quality science and have influenced the acceptance of quality as an important characteristic that leads to the successful operation of companies. The year 1987. is considered one of the most important in the history of quality development. The ISO 9000 series of standards was published for the first time under the title "Quality systems - a model for quality assurance in the design, development, production, assembly and servicing of products". The first edition of the ISO 9000 standard caused radical changes in quality management. By implementing a quality management system based on this international standard, organizations are provided with a number of potential benefits. Organizations gain the ability to deliver products and services that meet customer requirements and applicable legal and regulatory requirements, as well as to increase customer satisfaction.

2.4. The fourth industrial revolution and Quality 4.0

The beginning of the fourth industrial revolution is connected to the 21st century. At the world fair of industrial technologies in Hanover in 2011., the beginning of the era of Industry 4.0 was emphasized for the first time, i.e. launch of a platform for digitalization and networking of factories and all their components: products, machines, tools, people,... Industry 4.0 refers to new ways of communication between technologies and people and is currently happening around us. The digital influence from The third industrial revolution is expanding and merging with the physical and natural worlds. Industry 4.0 has brought great changes in technologies, and the industrial sector has found itself at the crossroads of many challenges. A characteristic of modern Industry 4.0 technologies is that they remove barriers between people and machines. Human participation is reduced to a minimum, which can be taken as a drawback of Industry

4.0. Unlike previous industrial revolutions that relied on one dominant technology, The fourth industrial revolution represents the convergence of cyber and physical technologies [3,7]. Some of the technologies that characterize Industry 4.0 are: Internet of Things - IoT , Big Data, Artificial Intelligence - AI, Cloud Computing - CC, Smart sensors, 3D printing, Machine Learning - ML in industry, etc., [7]. These technologies have the ability to influence the entire industry in terms of design, production, quality and delivery. In the available literature, it is stated that Industry 4.0 can be described as smart production, which is automated, digitized with minimal human participation in information exchange, decision-making and control. Modern technologies have made and are still making a great revolution in industry today, so we can witness many of its results such as: smart factories, smart machines and smart products. Intelligent vehicles, robots, sensors, 3D printers, etc., are just some of the products of Industry 4.0. Industry 4.0 has opened the way for the production of more sophisticated and complex products from different areas, such as: the automotive industry, the aviation industry and the military industry, which require more complex quality control and assurance systems, i.e. more sophisticated and precise tools for measurement and control, [12]. With the implementation of Industry 4.0 technologies in companies and their influence in the creation of high-quality products, the need to improve the existing approach to quality management was imposed. The existing concept of TQM has an approach to quality that is oriented towards product, process and organization with the application of mostly traditional tools for quality management with the use of manual measurements and calculations. With Industry 4.0, new possibilities open up, as challenges to quality management:

- expansion of the scope of access to quality towards customers and suppliers,
- increasing the volume of data on products, processes, customers, suppliers,
- use of digitization in quality control and management i
- monitoring and quality control in real time.

All the above challenges lead quality experts to find a new approach to quality that would correspond to the new industrial development. In this context, there are several conceptual frameworks, such as: the EFQM 2020 excellence model (European Foundation for Quality Management) and the integrated TQM approach, [3]. The evolutionary phase of quality in the era of the Fourth Industrial Revolution is called Quality 4.0. Quality 4.0 is an evolutionary sequence of quality development, as an upgrade to previous quality concepts. The new approach, supported by the new technologies of Industry 4.0, should respond to new requirements regarding the quality of products and services, for example through:

- automation of traditional quality control techniques,
- application of sensors with which an automatic review of the entire production population is performed in real time and
- automatic elimination of defective products.

Modern technologies make it possible to detect the potential cause of the failure and eliminate it before it causes additional costs. Locating the failure and stopping the operation of the machine, in order to avoid products with errors, with new technologies, is possible at any stage of production, [13]. In this way, high product quality is achieved and the possibility of a defective product reaching the customer's hands is eliminated. The Quality 4.0 conceptual framework uses existing theories and was created considering all the shortcomings of existing frameworks, such as the lack of clarity and comprehensiveness of data. It combines the current quality management system (TQM), operational practices and a modern approach to quality with the help of modern technologies. The conceptual framework of Quality 4.0 rests on four main pillars: TQM principles, Industry 4.0 technologies, big data management and real-time quality management, [4]. The goal of Quality 4.0 is to connect modern technologies with traditional quality methods, in order to optimize product and process performance.

3. Conclusion

We are witnessing that in the 21st century, organizations are facing market globalization and increased competition. It can be said with reason that the 21st century is the century of quality. Only those organizations that are capable of producing products of appropriate quality, which will satisfy increasingly demanding customers, can be competitive. Although the 21st century ushered in the Industrial Revolution 4.0, which brought with it new challenges in terms of quality management, Industry 5.0 is already knocking on our doors, which brings new challenges. While theoretical models such as TQM and Quality 4.0 provide comprehensive frameworks for managing quality, real-world implementation often lags. Many businesses still use outdated quality control techniques, especially in developing nations, and find it difficult to incorporate cutting-edge digital technologies and real-time data analytics into their quality systems. This gap between theory and practice highlights the need for more adaptable and phased strategies when introducing modern quality models into operational environments. However, organizations must take an innovative stance regarding quality, otherwise they will hardly survive and be competitive in the market.

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Influence of polymer solutions in mineral base oils on rheological characteristics

Samira Hotić[1], Emina Hotić[2], Pero Dugić[2], Osman Perviz[1]

[1]University of Bihać, Biotechnical Faculty, Bosnia and Herzegovina
[2]University of Banja Luka, Faculty of Technology, Bosnia and Herzegovina

E-mail: samira_hotic©yahoo.com

Abstract. Base oils are highly refined oils of mineral or synthetic origin, with defined structural composition and physical-chemical characteristics. They are used in the production of lubricants containing 80-90% base oils and 10-20% additives. Demands for oils and lubricants have greatly increased in recent decades, and constant growth is expected due to continuous innovations in the automotive industry. In order to ensure a certain quality of motor oils and that the finished products meet production specifications, it is necessary to know the physical and chemical characteristics of motor oils. Certain physical and chemical properties important for the quality of motor oils are achieved by the addition of additives. Additives for lubricants can be defined as agents that introduce new positive properties or improve already existing characteristics of lubricants. Additives for improving the viscosity index such as polymethacrylates and polyisobutenes are widely used as additives. In this work, the behavior of two types of viscosity improvers: olefin copolymer (OCP) and hydrogenated styrene-isoprene copolymer (SIP) in a solution of group II mineral base oils: SN100 and SN150 (4 cSt) was tested. Using the standard method ASTM D 445, the kinematic viscosity was determined, on the basis of which the relative and specific viscosity values were calculated. By monitoring the dependence of given viscosities on the polymer concentration in the base oil at temperatures of 40 ° C and 100 ° C, and by graphically presenting these dependencies, we examined the rheological characteristics of polymer solutions in mineral base oils. Therefore, the paper tries to examine which of the viscosity improvers has the most favorable effect on increasing the viscosity and viscosity index, that is, the effect on the temperature characteristics of the prepared base oil solutions.

1. Introduction

In the modern world, there is no branch of industry in which polymers and polymer products are not represented, from the food industry, textile industry, agriculture, shipbuilding, automotive industry, etc. In addition to all the mentioned applications of polymers, one of the most important is in the production of motor oils, where polymers are added as additives and primarily affect the rheological properties of motor oils. [1]

Base oils are highly refined oils of mineral or synthetic origin, with defined structural composition and physical-chemical characteristics. They are used in the production of lubricants containing 80-90% base oils and 10-20% additives. [2]

2.Theoretical part

2.1. Chemical composition of base oils

The composition and structure of chemical compounds present in base oils depend on the composition of crude oil, i.e. from its origin, because mineral oils are obtained from oil. In addition to hydrocarbons, which are the basic ingredients, organic compounds containing heteroatoms such as nitrogen, sulfur and oxygen are also present in oil. [3]

2.2. Classification of base oils

According to their origin, base oils can be divided into:

- Mineral base oils
- Synthetic base oils
- Vegetable base oils

3.Basic physicochemical properties of base oils

The quality of the base oil is prescribed and ensured by the minimum requirements of physico-chemical properties, which are defined by the standard, and are checked by appropriate standard test methods.

3.1. Density

The density of base oils is a physical characteristic that depends on the temperature, molecular weight and structural composition of the oil. Using standard methods, the density of oil is determined at 15 ° C, and is expressed in the unit kg/m ^{3}. The density of base oils ranges between 860-980 kg/m ^{3}.

3.2. Viscosity

Viscosity is one of the basic characteristics of fluids (lubricants-oils) in addition to density, and is a measure of internal friction, which acts as a resistance to changing the position of molecules in the flow of liquids when they are under the action of shear stress. The reciprocal property of viscosity is fluidity or the property of flowing.

In practice, viscosity can be expressed as dynamic and kinematic viscosity. Through the fluid density, the relationship between them is determined:

$$\nu = \frac{\eta}{\rho} \tag{1}$$

where is:

η- dynamic viscosity of the fluid [Pa·s]

ν– kinematic viscosity of the fluid [m ^{2} /s]

ρ- fluid density [kg/m ^{3}]

3.3. Viscosity index

Viscosity and viscosity index are extremely important characteristics and they mainly determine the possibility of using an oil. The viscosity index (IV) is an empirical number

that expresses the change in viscosity depending on the temperature change of an oil. It is necessary that the viscosity changes as little as possible with temperature changes, so that the lubricant can successfully perform its function under different operating conditions. [4]

3.4. Additives

Additives improve the lubricating ability of base oils by enhancing the desirable properties of the base oil or by adding some new properties to the final lubricant

Additives for improving the viscosity index are most often used in the production of *multigrade motor oils* and have the following characteristics:

- at low temperatures, they keep the oil sufficiently liquid, so that when starting the engine with low internal friction, minimal engine power is consumed and enables safe engine start.
- at high temperatures they give the oil a higher viscosity, which ensures the necessary oil layer thickness and low oil consumption [5]

4. Experimental part

The experimental part of the work was carried out in the laboratory of the company "Tehnosint" with its seat in Laktaši, and includes testing the behavior of the polymer in the base oil solution.

As part of the experimental part of the work, measurements of the following characteristics were performed:

- kinematic viscosities 40 ° C and 100 ° C
- viscosity index

Based on the measured values of the above characteristics, values were calculated for:

- relative viscosity at 40 ° C and 100 ° C
- specific viscosity at 40 ° C and 100 ° C

The study of the influence of the concentration of polymer additives on the viscosity and viscosity index of motor oil was examined in the range of concentrations from 2.00% to 10.00% for SIP, and in the range of concentrations from 2.00% to 10.00% for OCP. The measurements of the mentioned characteristics were performed before and after the addition of the viscosity index improver. In this way, changes and the influence of improvers on the properties that are of key importance for the use of motor oil were monitored. Knowing the physical and chemical properties of base oils, as well as polymer additives, enables reliable quality control during production and obtaining products that meet the prescribed specifications. During the test, the standards for the applied methods were adhered to, which describe and define the test method and apparatus, and prescribe the method of verifying the results and the accuracy of the method.

4.1. Work materials

For the test, two types of base oils obtained by the process of solvent technology were used, the so-called *solvent neutral*, which are group II base oils: SN100 (label B_1) and SN150 (label B_2). Two types of polymers were used as viscosity index improvers: olefin copolymer (OCP) and hydrogenated styrene-isoprene copolymer (SIP), from which the concentrations shown in the table were prepared. All tested base oils and polymers are commercial products of well-known European manufacturers.

Tabele 1. Series of different viscosity improver concentrations.

Polymer	Polymer designation	Polymer concentrations in base oils [%]				
SIP	P_1	2.0	4.0	6.0	8.0	10.0
OCP	P_2	2.0	4.0	6.0	8.0	10.0

4.2. Working methods

The standard method ASTM D 445 prescribes the procedure for determining kinematic viscosity. The principle of determination is based on measuring the time for which a certain volume of liquid passes freely through a calibrated capillary of a glass viscometer, under repeatable conditions at a known and constant temperature. Kinematic viscosity is the product of the measured flow time and the constant of the calibrated, or calibrated, viscometer.

4.3. Preparation of polymer solutions in base oils

At the beginning of the experimental part of the work, it is necessary to weigh certain polymer masses, and the values of the weighed masses are shown in the table. Given that it is about the same concentrations of polymer solutions in base oils, we will get the same masses of polymers: SIP (P_1) and OCP(P_2) for further tests . The solutions were prepared in beakers of different volumes with the contents heated up to 100 ° C and constant mixing (Figure 3.1) in order to homogenize and more efficiently dissolve the polymer in the base oil. The study of the influence of the concentration of polymer additives on the viscosity and viscosity index of motor oil was examined in the same range of concentrations from 2.0%m/m to 10.0%m/mi for olefin copolymer (OCP) and for hydrogenated styrene-isoprene. copolymer (SIP).

Table 2. Masses of polymers SIP (P_1) and OCP (P_2) in base oils SN 100 (B_1) and SN 150 (B_2).

Sample code	Base oil (B_1 and B_2)	Polymer (P_1 and P_2)				
Polymer concentration [%m/m]	-	2.0	4.0	6.0	8.0	10.0
$m_{polymer}$ [g]	-	4.0	8.0	12.0	16.0	20.0

$m_{base\ oil}$ [g]	200	196	192	188	184	180

4.4. Apparatus for measuring kinematic viscosity

A viscometer with a calibrated glass capillary is used to measure kinematic viscosity. The most commonly used viscometers are the Ubbelohde viscometer for transparent liquids and the Cannon-Fenske viscometer for opaque liquids.

Figure 1. Ubbelohde viscometer (left) and oil bath viscometer (right).

5.Results and discussion

The figure shows a graphical comparison of the values of kinematic viscosities determined at temperatures of 40 °C and 100 °C of the tested base oils. The diagram shows that the kinematic viscosity of the tested base oils is higher at a temperature of 40 ° C than at 100 ° C for both types of base oils. The SN 150 group base oil has higher kinematic viscosity values at 40 ° C and 100 ° C compared to the SN 100 base oil and thus a lower viscosity index.

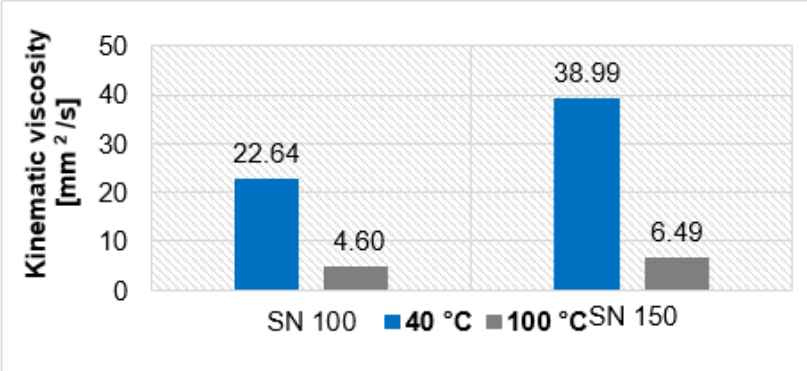

Figure 2. Graphical comparison of kinematic viscosity of tested base oils.

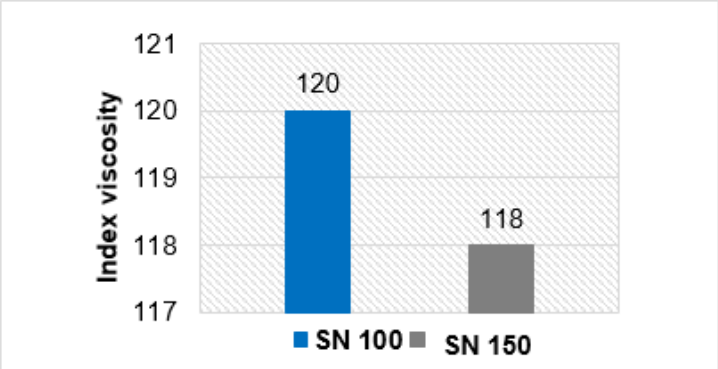

Figure 3. Graphical comparison of viscosity index of tested base oils.

Table 3. Characteristics of SIP solution in base oil SN 150.

	Sample code	Base oil B_2	Polymer solution in base oil ($P_1 B_2$)				
Characteristics	Polymer concentration [%m/m]	-	2.0	4.0	6.0	8.0	10.0
	Viscosity at 40 ° C [mm ² /s]	32.493	40.465	44.652	51.163	56.512	64.809
	Viscosity at 100 ° C [mm ² /s]	5.731	6.901	7.559	8.627	9.448	10.845
	IV	118	130	136	146	150	159
	$\eta_{rel.}$ at 40 ° C	-	1.25	1.37	1.58	1.74	2.00
	$\eta_{spec.}$ at 40 ° C	-	0.25	0.37	0.58	0.74	1.00
	η_{order} at 40 ° C						
	$\eta_{rel.}$ at 100 ° C [cm ³ /g]	-	1.20	1.32	1.51	1.65	1.90
	$\eta_{spec.}$ at 100 ° C		0.20	0.32	0.51	0.65	0.90
	η_{order} at 100 ° C [cm ³ /g]	-					

Table 4. Characteristics of SIP solution in base oil SN 100.

	Sample code	Base oil B_1	Polymer solution in base oil ($P_1 B_1$)				
Characteristics	Polymer concentration [%m/m]	-	2.0	4.0	6.0	8.0	10.0
	Viscosity at 40 ° C [mm ² /s]	22.636	25.116	28.449	31.706	35.117	41.783
	Viscosity at 100 ° C [mm ² /s]	4.601	5.094	5.669	6.326	6.983	8.106
	IV	120	135	144	155	164	171
	$\eta_{rel.}$ at 40 ° C	-	1.11	1.26	1.40	1.55	1.85
	$\eta_{spec.}$ at 40 ° C	-	0.11	0.26	0.40	0.55	0.85
	η_{order} at 40 ° C [cm ³ /g]	-					
	$\eta_{rel.}$ at 100 ° C	-	1.11	1.23	1.37	1.52	1.76
	$\eta_{spec.}$ at 100 ° C	-	0.11	0.23	0.37	0.52	0.76
	$\eta_{red.}$ at 100 ° C [cm ³ /g]	-					

Table 5. Characteristics of OCP solution in base oil SN 150.

	Sample code	Base oil B_2	Polymer solution in base oil (P_2B_2)				
Characteristics	Polymer concentration [%m/m]	-	2.0	4.0	6.0	8.0	10.0
	Viscosity at 40 ° C [mm ² /s]	33.493	41.628	47.442	53.256	60.000	66.590
	Viscosity at 100 ° C [mm ² /s]	5.731	7.148	7.969	8.873	9.941	10.845
	IV	118	134	139	146	152	154
	$n_{rel.}$ at 40 ° C	-	1.28	1.46	1.64	1.85	2.05
	$n_{spec.}$ at 40 ° C	-	0.28	0.46	0.64	0.85	1.05
	η_{order} at 40 ° C [cm ³ /g]						
	$n_{rel.}$ at 100 ° C	-	1.25	1.40	1.55	1.73	1.90
	$n_{spec.}$ at 100 ° C		0.25	0.40	0.55	0.73	0.90
	η_{order} at 100 ° C [cm ³ /g]	-					

Table 6. Characteristics of OCP solution in SN 100 base oil.

	Sample code	Base oil B_1	Polymer solution in base oil (P_2B_1)				
Characteristics	Polymer concentration [%m/m]	-	2.0	4.0	6.0	8.0	10.0
	Viscosity at 40 ° C [mm ² /s]	22.636	24.806	27.920	33.144	37.442	42.326
	Viscosity at 100 ° C [mm ² /s]	4.601	5.094	5.601	6.513	7.312	8.051
	IV	120	138	144	154	164	166
	$n_{rel.}$ at 40 ° C	-	1.10	1.23	1.46	1.65	1.87
	$n_{spec.}$ at 40 ° C	-	0.10	0.23	0.46	0.65	0.87
	η_{order} at 40 ° C [cm ³ /g]						
	$n_{rel.}$ at 100 ° C	-	1.11	1.22	1.42	1.59	1.75
	$n_{spec.}$ at 100 ° C		0.11	0.22	0.42	0.59	0.75
	η_{order} at 100 ° C [cm ³ /g]	-					

6.Conclusions

Based on theoretical knowledge and the results of experimental testing, we can conclude the following:

1. The solubility of the tested polymers in all tested base oils is directly correlated with the content of aromatic hydrocarbons in the base oils. Tested viscosity improver samples were better dissolved in base oil SN 150 due to the slightly higher content of aromatics in this oil compared to base oil SN 100.
2. The increase in viscosity and viscosity index of the base oil solution increases with the increase in the concentration of polymer additives in the solution, regardless of the type of base oil. An increase in the concentration of polymer additives leads to an increase in the total volume of polymer micelles in the prepared solutions, and this very fact results in an increase in the viscosity index. Viscosity index values

depend on the type, chemical structure and molecular weight of the polymer, for the same type of base oil.

3. Of all the tested polymer solutions, the highest viscosity index was achieved using the polymer additive SIP (hydrogenated styrene-isoprene copolymer) in base oil SN 100 and is 171, while the lowest viscosity index was achieved using the polymer additive OCP (olefin copolymer) in base oil SN 150 and is 154.
4. The values of kinematic viscosity at 40 ° C and 100 ° C in both base oils show higher values with the use of the viscosity improver OCP. The given values are the highest in base oil SN 150. The increase in kinematic viscosity in both base oils has an exponential dependence, which indicates a good agreement between the experimental results and the mathematical function obtained by computer processing of the results.
5. The highest values of reduced and specific viscosity at 40 ° C and 100 ° C were achieved using the viscosity improver OCP in the SN 150 base oil.
6. The best properties are possessed by a polymer that improves viscosity and increases the viscosity index, which means that such motor oil is resistant to changes in viscosity with temperature changes. In the comparison of the two tested polymer additives, the polymer additive SIP is more efficient as a viscosity improver.

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Heavy metals in soil and wild plants at sites exposed to industrial and traffic pollution

Tanja Veladžić[1], Merima Toromanović[2], Vildana Jogić[2], Adel Sarajlija[2] and Mirsad Ičanović[2]

[1]Agricultural Institute, Bihać, Bosnia and Herzegovina
[2]University of Bihać, Biotechnical faculty, Bosnia and Herzegovina

E-mail: merima.toromanovic@unbi.ba

Abstract. Soil pollution with heavy metals is a serious environmental issue that affects soil quality, plant health, as well as animal and human health. Heavy metals such as cadmium (Cd), lead (Pb), and iron (Fe) can accumulate in the soil through various pollution sources. Certain plant species have shown potential in removing contaminants from the soil, but further research is needed to better understand their role in the bioremediation of contaminated areas. The aim of this research was to determine the concentration of heavy metals (cadmium – Cd, lead – Pb and iron – Fe) in the soil and wild plants such as dandelion (*Taraxacum officinale agg*.) and wild mugwort (*Artemisia vulgaris L.*) at sites considered exposed to various sources of pollution, such as roadways, industrial zones, and agricultural land. Plant and soil samples were collected in July, with a total of 6 plant samples and 3 soil samples taken from three locations. The concentration of heavy metals in the plant material was generally in accordance with legal regulations. The exception was dandelion at two sites, where cadmium concentrations were above the Maximum Permissible Concentration (MPC) (1.027 mg/L and 1.070 mg/L). Regarding soil samples, the concentrations of cadmium and lead were above the MPC in three samples. The highest concentration of cadmium (2.608 mg/L) and lead (2.425 mg/L) was found in the soil near the "Petrol" gas station, where the lowest soil pH value (6.13) was also measured. Special emphasis was placed on the relationship between soil pH value, humus content, and the presence of heavy metals. All laboratory analyses were conducted at the accredited laboratory of the Agricultural Institute of Una-Sana Canton, in accordance with the requirements of the BAS EN ISO 17025 standard. This research aimed to determine whether specific wild plant species could contribute to reducing the concentrations of heavy metals in contaminated soils, taking into account variations at the studied sites.

1. Introduction

Heavy metals can be found naturally in the soil, however, anthropogenic activity increases their concentration, which can be harmful to plants, animals and humans. Heavy metals have an extremely toxic effect on all living things because they accumulate in the body without the possibility of excretion. Once they reach the soil, they passively remain in the soil pores or actively bind to the colloidal complex. Current soil pollution is one of the vital environmental problems that poses a particular threat to human

health due to the widespread presence of heavy metals, their toxicity and bioaccumulation (accumulation in living tissues of plants and animals). Accumulated metals in the soil are released into various ecosystems through groundwater, rivers and even crops, thus posing a serious threat to human health [1].

The main representatives of inorganic pollutants are heavy metals that pollute the soil and can have dangerous consequences for the environment, animals and human health. A large number of studies show that plants have a huge genetic potential that enables the removal of toxic metals from the soil, so they can play an important role in the phytoremediation process [2].

Agricultural soils, including those under fruit production, are particularly susceptible to degradation, given the numerous, often radical, technical and technological interventions in plant cultivation, which lead to environmental pollution. The problem of heavy metals in the soil-water system is becoming increasingly relevant today [3].

Phytoremediation is considered an environmentally friendly soil remediation, often referred to as green remediation [4]. Phytoremediation is defined as the effective use of plants to remove, detoxify or immobilize pollution in the growing area (soil, water, sediments) through biological, chemical or physical processes that occur naturally in plants. These include plants that grow rapidly from the contaminated medium during a specific growth period, to remove contaminants from the reaction mixture, or to facilitate immobilization (binding/stopping) or degradation (detoxification) of contaminants.

The biggest problem is inorganic pollutants which, unlike organic ones, are not biodegradable into smaller or non-toxic compounds. The phytoremediation plant species must be a non-invasive species that animals do not they like to eat. The plant is chosen according to its ability to extract toxins from the environment, adaptability to local climatic conditions, large production of green mass, the depth to which the root penetrates, compatibility with the type of soil to be rehabilitated, the speed of growth, the simplicity of planting and maintenance, and the ability to absorb large amount of water [5]. Research has shown that plant species such as dandelion (*Taraxacum officinale agg*.) and wild mugwort (*Artemisia vulgaris L.)* which belong to the Asteraceae family, are used as hyperaccumulators. Hyperaccumulators are a subgroup of accumulator species, which accumulate extremely high concentrations of metals in leaves and other above-ground parts [6].

2. Materials and methods

For the purpose of investigating the presence of heavy metals in plant material in industrial zones, major roads and agricultural areas in the area of the City of Bihać, plant species were selected according to the following criteria: that they are wild species or weed species known as hyperaccumulators of heavy metals, that they are common in

urban areas, that they create significant biomass, that they have the ability to phytoaccumulate heavy metals and that they can be removed by mowing.

The aim of this research was to determine the concentration of heavy metals (cadmium – Cd, lead – Pb and iron – Fe) in the soil and wild plants such as dandelion (*Taraxacum officinale agg*.) and wild mugwort (*Artemisia vulgaris L*.) at sites considered exposed to various sources of pollution, such as roadways, industrial zones, and agricultural land.

2.1 Characteristics of selected plant species

Dandelion – *Taraxacum officinale agg.*

A plant from the Asteraceae family. It is a perennial herbaceous plant with yellow inflorescences, called heads, which are composed of a large number of tubular and linguineous flowers. The leaves are serrated and form a rosette from which a hollow stem grows, at the top of which the inflorescences develop. The dandelion root is spindle-shaped. It flowers from April to September. It is a suitable bioindicator of the degree of environmental contamination with heavy metals.

Figure 1. Dandelion – *Taraxacum officinale agg.* [7].

Wild mugwort - *Artemisia vulgaris L.*

A plant from the Asteraceae family. Perennial up to 1.5 m tall. The stem is branched in a broom-like manner, brown or reddish, woody in the lower part. The leaves are single-pinnately incised, glabrous and dark green on the upper side, and white and more or less hairy on the lower side. In the upper part of the stem, the leaves are simple (undivided) or at most three-lobed. At the tips of the branches, small, yellowish or reddish flowers develop in heads that are united in spike-like, and sometimes cluster-like inflorescences.

It flowers from June to September. It is a suitable bioindicator of the degree of environmental contamination with heavy metals.

Figure 2. Wild mugwort - *Artemisia vulgaris L.* [8].

Today, there are various methods of monitoring the state of soil pollution, and we expect that phytoremediation with the above-mentioned plant species will prove to be a very useful and effective method for reducing the concentration of heavy metals in the soil.

This research was carried out in three localities in the area of the City of Bihać, namely:

1. Orchard "Bakšaiš"
2. Gas station "Petrol" and
3. Path of the "Robot" army

Soil and plant samples were taken at the three mentioned locations in the area of Bihać in June 2024, and they were delivered to the laboratory of the Agricultural Institute of the Una - San Canton. We took a total of 9 samples, one each of soil, dandelion and wormwood from all three localities. Soil samples were taken with a soil sampling probe, and samples of dandelion and wild mugwort plants were taken after swathing in June.

After submitting the soil samples to the laboratory, the humus content was determined in accordance with the Instruction for the method for determining humus in the soil according to Tjurin (Instruction-UL-9), because the mass fraction of humus is significant for determining the degree of soil contamination with heavy metals according to the Rulebook on determining the permitted amounts of harmful and dangerous substances in the soil and their testing methods.

The pH value of the soil was determined in accordance with the Instruction on the method for determining the pH value in the soil BAS ISO 10390:2009 (Instruction - UL-5).

The sample preparation included the following procedures:

- Recording of samples,
- Sample drying,
- Shredding of samples,
- Homogenization of samples,
- Digestives and
- Analyzes of prepared samples on the Atomic Absorption Spectrophotometer (AAS).

All laboratory analyses were performed in the laboratory of the Agricultural Institute of the USK, which is an accredited laboratory in accordance with the requirements of the BAS EN ISO 17025 standard in terms of qualification for performing physical and chemical soil tests.

The obtained research results were statistically processed using standard descriptive statistical methods.

3. Results and discussion

According to the maximum permitted amounts of harmful and dangerous substances in the soil (Official Gazette of the FBiH 52/09) it is important to emphasize that iron is not regulated by the said Ordinance, i.e. no limit values are set for the reason that it is not a contaminant, i.e. it is not poisonous! For cadmium (Cd) the limit value is 1.5 ppm and for lead (Pb) the limit value is 1.00 ppm.

According to the Ordinance on the maximum permitted quantities for the determination of contaminants in food (Official Gazette of BiH 68/14), for wild mugwort and dandelion/food supplement, the limit value for cadmium (Cd) is 1.0 ppm and for lead (Pb) is 3.00 ppm.

Table 1. pH value and humus content in the analysed soil samples.

Sample	pH value	Humus content
1	7.133	3.854%
2	7.011	3.256%
3	7.385	4.564%

[a]1 - soil - Petrol station; 2 – soil -Army road; 3 - soil - Bakšaiš Orchard

The results of soil analysis indicate that the pH values range from 7.011 to 7.385, which classifies the soil as neutral to slightly alkaline. Such pH levels are favourable for most plant species, as they allow for optimal availability of nutrients, particularly phosphorus, potassium, and micronutrients.

The humus content ranges from 3.256% to 4.564%, which is considered moderately to well humified soil. Humus significantly contributes to soil fertility by improving its structure, water retention capacity, and microbiological activity. Values

above 3% indicate a satisfactory level of organic matter, which is essential for sustainable soil use and the preservation of its fertility.

The analysed soil samples exhibit favourable chemical properties, making them suitable for agricultural production, especially for crops that prefer neutral soils and a moderately high humus content.

Table 2. Descriptive statistics of pH value and humus content in the analysed soil samples.

	N	Minimum	Maximum	Mean	Std. Deviation
pH	3	7.01	7.39	7.1763	0.19073
Humus	3	3.25	4.56	3.8867	0.65577

Table 2 presents the results of descriptive statistics for pH value and humus content in the soil samples collected from three locations. The pH value in the soil samples ranges from 7.01 to 7.39, while the humus content ranges from 3.25 to 4.56.

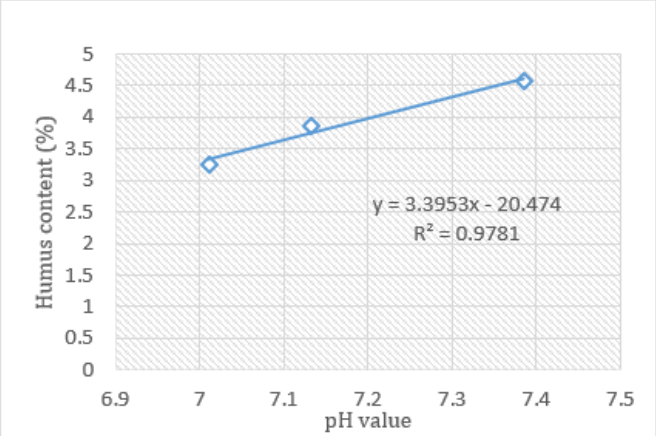

Figure 3. Correlation between pH value and total humus content in soil samples

To confirm the relationship between pH value and humus content in the examined soil samples, a correlation analysis was conducted. The results indicated a strong positive correlation (R^2=0.97), suggesting that as the pH value of the soil increases, the humus content tends to increase as well. This strong linear relationship implies that soil pH may play a significant role in influencing organic matter accumulation, which is crucial for soil fertility and plant growth. The high R^2 value also indicates a high level of consistency in the observed trend across the analysed samples.

Table 3. The concentration of heavy metals in soil and plant material.

Sample	Lead (Pb) (mg/L-ppm)	Cadmium (Cd) (mg/L-ppm)	Iron (Fe) (mg/L-ppm)
1	0,00	0.00	0.00
2	0.778	1.050	0.040
3	0.996	0.857	0.021
4	1.257	0.872	0.141
5	1.361	1.027	0.055
6	1.463	0.957	0.248
7	1.600	1.070	0.148
8	2.425	2.608	48.32
9	2.019	1.691	45,26
10	2.103	1.913	40.49

[a]1 – Blind test (BT)

2 - Wild mugwort – Petrol station
3 - Wild mugwort – Army road
4 - Wild mugwort – Bakšaiš Orchard
5 - Dandelion - Petrol station
6 - Dandelion - Army road
7 - Dandelion - Bakšaiš Orchard
8 - Soil - Petrol station
9 - Soil -Army road
10 - Soil - Bakšaiš Orchard

The analysis for testing heavy metals was performed after thorough acid digestion. The results were read on an atomic absorption spectrophotometer.

In the soil samples (8, 9 and 10) taken from all three localities, the content of lead (Pb) is below the limit values (less than 50 mg/kg). When it comes to the content of cadmium (Cd), based on the test results, it is evident that in all samples the cadmium content is higher than the permitted values (more than 0.5 mg/kg). It is important to emphasize that iron (Fe) it is not regulated by the Ordinance on maximum permitted amounts of harmful and dangerous substances in the soil (Official Gazette of FBiH 52/09). No limit values have been determined for this metal because it is not a contaminant, i.e. it is not toxic.

The results show that the concentrations of lead (Pb) and cadmium (Cd) are significantly higher in the soil than in the plants, which is expected since the soil acts as a reservoir for these metals. This indicates a relatively low rate of metal transfer from the soil to the plants, which may be due to specific soil properties, pH values, as well as natural plant mechanisms that limit the uptake of toxic metals. Iron (Fe) shows exceptionally high values in the soil, especially at the Bakšaiš Orchard site, where its concentration is several times higher compared to the other two locations. This may be a result of the geological characteristics of the soil or local anthropogenic influences, which can further affect the mobility and bioavailability of other heavy metals.

In plant samples (2,3,4,5,6 and 7) taken from all three localities, the content of lead (Pb) is below the limit values (less than 3.00 ppm). When it comes to the content of cadmium (Cd), based on the obtained test results, it is evident that the cadmium content in the plant samples marked with 2, 5 and 7 is higher than the permitted values (more

than 1.00 ppm), while the cadmium content in the samples marked with 3, 4 and 6 is below the permitted value. In this case too, it is important to emphasize that iron (Fe) is not regulated according to the Ordinance on maximum permitted amounts for certain contaminants in food (Official Gazette of FBiH 68/14), i.e. no limit values have been determined for plants that are declared as a food additive. One of the biggest current problems in modern ecology and agroecology is soil pollution with heavy metals. According to the conducted research, the total amount of heavy metals is higher in plants and soils of urban areas, near the gas station and the main highway near the "Robot" shopping center, but the results obtained from samples taken in the orchard in Bakšaš are close to samples marked 2 and 3 because the orchard is also located near the road. The term "heavy metal" usually refers to chemical elements with a relative density greater than 5.0 g cm-3, which are metals or metalloids that have a toxic effect and are classified as major inorganic pollutants, but also include elements that organisms need in low concentrations or microelements [9].

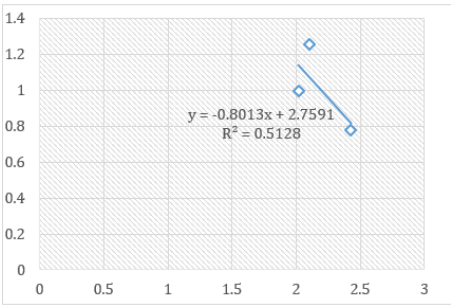

Figure 4. Correlation between soil samples and plant material in lead content

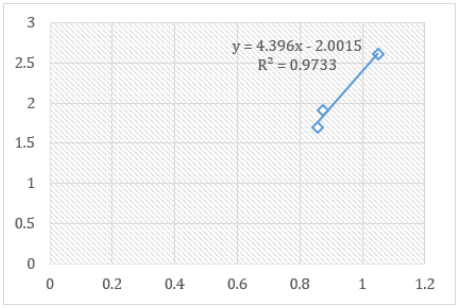

Figure 5. Correlation between soil samples and plant material in cadmium content

The correlation analysis revealed a strong positive correlation (R^2=0.9733) between the concentration of cadmium in the analysed soil samples and the plant material from the three different locations. This high coefficient of determination indicates that cadmium present in the soil is closely associated with its uptake and accumulation in plant tissues. Such findings emphasize the importance of monitoring cadmium levels in agricultural soils due to its potential impact on food safety and environmental health.

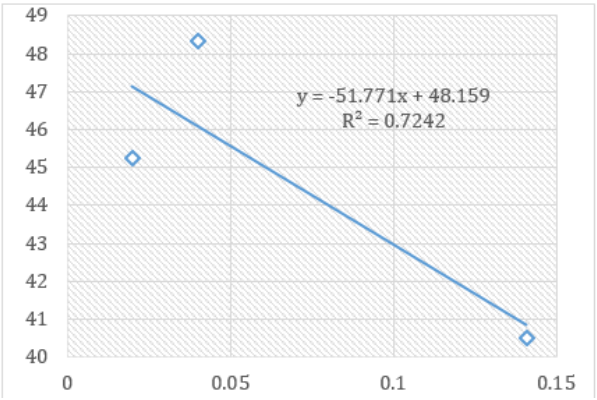

Figure 6. Correlation between soil samples and plant material in iron content

The correlation analysis demonstrated a positive correlation (R^2=0.7242) between the concentration of iron in the analysed soil samples and the corresponding plant material. This indicates a relatively strong relationship between soil iron levels and its accumulation in plant tissues, suggesting that iron availability in the soil plays a significant role in plant uptake. Although not as high as in the case of some other heavy metals, this level of correlation still points to a consistent soil-to-plant transfer pattern for iron, which is essential for understanding nutrient dynamics and potential environmental implications.

Plant species show different capacities for heavy metal accumulation, with both wild mugwort and dandelion recording lower concentrations of Pb and Cd compared to the soil. These results suggest that these species may have a certain ability to filter or selectively absorb metals, making them potential indicators of pollution and candidates for phytoremediation.

According to research by Jakovljević et all [2], who conducted a similar study of heavy metal concentrations in the Velebit, Biokovo, Učka, Lonjsko polje and Medvednica Nature Parks, it showed high to very high levels of soil contamination with lead (Pb). Increased concentrations of lead (Pb), copper (Cu), zinc (Zn) and cadmium (Cd) were found in lowland forest areas of central Croatia. The cause of the increased concentrations of these metals is probably leaching from treated agricultural land. According to available data, the soil of the metropolitan area is significantly more heavily polluted and has increased concentrations of lead and other heavy metals compared to the soil in forest ecosystems due to the proximity of main roads, i.e. pollution from local sources. The level of soil contamination in the Zagreb metropolitan area with lead and other heavy metals can be assessed as ecologically unacceptable. Their research included areas and soil used for agriculture, although part of the work was done on areas that have other uses - forests, abandoned and uncultivated land, urban soils and others.

The research highlights the importance of continuous monitoring and analysis of both soil and plants at various locations in Bosnia and Herzegovina, with the aim of assessing the risk of heavy metal contamination and its impact on the environment and human health. It is especially important to monitor sites with higher metal concentrations in the soil and to further investigate the factors that influence the transfer and accumulation of metals in plant species.

4. Conclusions

Heavy metal pollution poses a serious threat to the environment (soil, water, plants, animals and humans) on a global scale due to their toxicity, persistence and bioaccumulation in living organisms. Soil remediation is possible, however uneconomical due to the high cost, mainly by phytoremediation, but only in a small area. Some of the conclusions of the research are:

- The concentrations of lead (Pb) and cadmium (Cd) were significantly higher in soil samples compared to plant samples, confirming that soil acts as the main reservoir for these metals.
- In all soil samples, the cadmium content exceeded the permitted limit value (1.5 ppm), while the lead content remained below the maximum allowed values.
- In plant samples, the lead content did not exceed the allowed limit (3.0 ppm), while cadmium exceeded the permitted value (1.0 ppm) in samples from the petrol station and orchard locations, indicating the influence of proximity to traffic.
- Although the concentration of iron (Fe) was exceptionally high, particularly at the Bakšaiš location, it is not classified as a pollutant because it is non-toxic, and therefore no limit values are prescribed for it.
- The soil samples exhibit neutral to slightly alkaline pH values and satisfactory humus content, making them suitable for agricultural production and indicating a relatively healthy ecosystem in chemical terms.
- The analysis clearly demonstrated a strong positive correlation between soil pH and humus content in the examined samples (R^2=0.97). This indicates that an increase in soil pH directly influences the accumulation of organic matter, which is essential for soil fertility and healthy plant growth. The high coefficient of determination confirms the reliability and consistency of this trend across all analysed samples.
- The highest values of heavy metals were recorded in samples from urban locations near the petrol station and the main road, pointing to a clear anthropogenic influence (traffic, pollution from populated areas).
- Wild mugwort and dandelion show the ability to selectively accumulate heavy metals, making them useful for monitoring pollution and potentially for phytoremediation of contaminated areas.

- The statistical analysis confirmed the existence of positive correlations between the concentrations of heavy metals (cadmium, lead, and iron) in soil samples and their corresponding levels in plant material collected from three different locations. Among the analyzed elements, cadmium showed the strongest correlation (R^2 = 0.9733), indicating a high potential for transfer from soil to plants. These findings suggest that the uptake of these elements by plants is influenced by their availability in the soil, highlighting the importance of monitoring heavy metal content.

Continuous monitoring of heavy metals in soil and plants is crucial for risk assessment and the protection of human health and the environment, especially at locations exposed to pollution from traffic and industry. This challenge is a challenge that humanity is struggling to overcome, especially in the systematic and mandatory control of heavy metals in food, although some success has been achieved by reducing exhaust gases and industrial pollution. Phytoremediation and sowing of hyperaccumulator plants as pre- or intercrops can significantly reduce the uptake of heavy metals from the soil, although the problem remains of what to do with the plants, or their ashes, when they contain high concentrations of heavy metals.

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Seasonal variations in morphometric parameters of Phoxinellus alepidotus, Heckel 1843 from Lake Šator

Subha Avdić[1], Azra Bakrač [1], Avdul Adrović[2], Edina Hajdarević[2], Samira Dedić[1] and Vildana Jogić[1]

[1]University of Bihać, Faculty of Biotechnology, Bosnia and Herzegovina
[2]University of Tuzla, Faculty of Science, Bosnia and Herzegovina

E-mail: subhaavdic8@gmail.com

Abstract: The presence of Phoxinellus alepidotus (Heckel, 1843) as a regional endemic of the Adriatic basin has been recorded in Lake Šator. When it comes to the variability of morphometric parameters of the Phoxinellus alepidotus in relation to seasons, available data are very scarce. Therefore, the aim of this study was to determine the variability of the Phoxinellus alepidotus morphometric parameters in relation to seasons, as well as the influence of physico-chemical water parameters on the morphometric characteristics of individual Phoxinellus alepidotus. Water sampling and the determination of morphometric parameters of Phoxinellus alepidotus from Lake Šator were conducted during the spring-autumn season. A significant difference in physico-chemical water parameters was recorded for temperature, pH, O_2 concentration, nitrates and total nitrogen, while no statistically significant difference was observed for the other analysed parameters. The analysed individual Phoxinellus alepidotus had higher values of total and standard length, as well as mass, in autumn compared to spring. However, only the values of Fulton's condition factor were higher in spring than in autumn. The values of Fulton's condition factor indicate good nutritional status of the specimens in both seasons. No statistically significant difference was recorded for any of the analysed morphometric parameters.

Keywords: *Phoxinellus alepidotus*, morphometric parameters, Lake Šator

1. Introduction

Monitoring of ichthyopopulations is very important from numerous perspectives, including the assessment of the health status of fish as well as the environment in which they inhabit. When it comes to the conservation of endemic fish species, it is essential to understand their biology and ecology, which involves the investigation of morphometric parameters of fish [1]. It is crucial to preserve endemic species not only

as natural resources but also due to their significant impact on the natural environment [2, 3]. Morphometric parameters of fish are critically important in terms of growth, health, and adaptation to environmental conditions. Understanding morphometric parameters, diet, and reproductive traits of fish is a key factor for species identification in their natural habitat [4]. Morphological differences among fish are influenced by various ecological factors such as temperature, salinity, dissolved oxygen, radiation, water depth, and current flow [5, 6, 7, 8]. Fulton's condition factor is used as an indicator of the general health status at the individual or population level of fish [9]. This parameter effectively reflects the general condition of fish, as well as changes that occur depending on location and physiological cycles in the life of fish [10]. It also provides important information about the quality and suitability of the environment [11, 12] and reflects the interaction between abiotic and biotic factors under the physiological conditions of fish [13]. Regarding the study of morphometric parameters of the species **Phoxinellus alepidotus**, data do exist but are scarce. However, there is a lack of information concerning the variation of morphometric parameters of this species in relation to seasonality. Therefore, the aim of this study was to determine the variability of morphometric parameters of **Phoxinellus alepidotus** in relation to seasonality, as well as the influence of physico-chemical water parameters on the morphometric traits of individuals from Šator Lake.

2. Materials and Methods

2.1 Study Site

Mount Šator extends northwest of Glamoč at a distance of approximately 30 km, and southeast of Bosansko Grahovo at a distance of about 40 km. The highest peak of Šator is Veliki Šator, with an elevation of 1827 meters, and beneath it lies Šator Lake, of glacial origin, at an altitude of 1450 meters above sea level. According to [14] Šator Lake is 337 meters long, 127 meters wide, and 8 meters deep, and it is located between 44°09'58.6'' N latitude and 16°36'04.8'' E longitude.

2.2. Water sampling and physicochemical parameters

Water samples from Šator Lake were collected in accordance with water sampling regulations. In spring and autumn, 1000 ml water samples were taken from a depth of approximately 20–30 cm. A total of 20 parameters were analyzed as part of the physico-chemical analysis. Water temperature, pH, electrical conductivity, and dissolved oxygen concentration were measured on-site, while the remaining parameters were analyzed using standard methods according to [15] in the laboratories of the Faculty of Biotechnical Sciences.

2.3. Electrofishing

Individuals of *Phoxinellus alepidotus* were collected in both seasons from Šator Lake using an electrofishing device, model ELT62II GI HONDA GCV160. After undergoing galvanotaxis and galvanonarcosis, the fish were collected using dip nets and transferred into buckets filled with water that was continuously oxygenated using an aerator.

2.4. Morphometric parameters

In this study, the following morphometric parameters were analyzed for 20 *Phoxinellus alepidotus* individuals in spring and 20 individuals in autumn: total length, standard length, weight, and Fulton's condition factor, calculated using the formula [16]:

$K = W \times 100 / L^3$

Where:

W – Weight of the fish in grams

L – Standard length of the fish in centimetres

2.5. Statistical analysis

The statistical analysis in this study involved the use of descriptive and analytical statistics. Therefore, the data were processed using software programs such as Excel 2013 and Past 4.3. One-way ANOVA was used for variance analysis with a confidence interval of 95% and an absolute precision of 5%.

3. Results

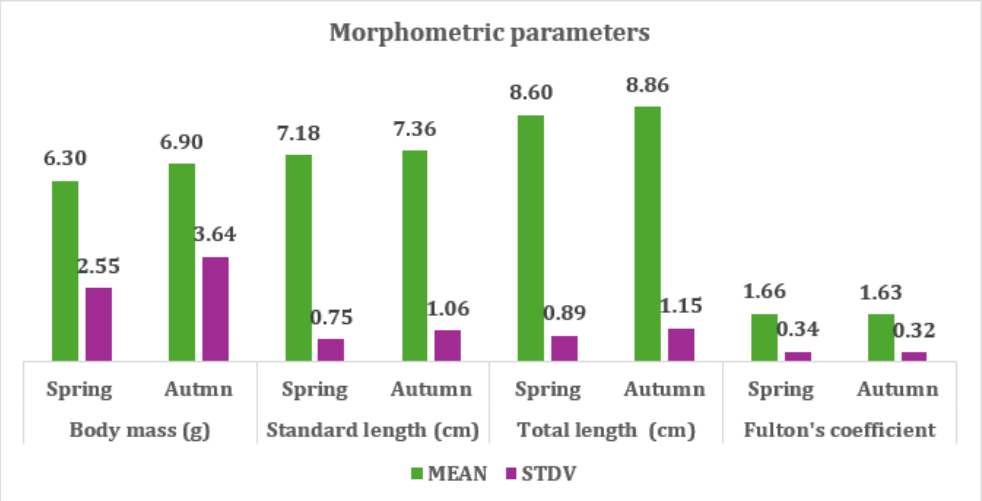
The results of the physicochemical parameters are presented in tabular form (Table 1). Based on the obtained results, it can be observed that the mean values for temperature, O_2 concentration, oxygen saturation, suspended solids, fluorides, nitrites, and dry matter were higher in spring, while the other parameters (pH, electrical conductivity, turbidity, BOD_5, nitrates, chlorides, phosphorus, phosphates, ammonia, total nitrogen, and sulphates) had higher values in autumn, except for ash content, which showed identical mean values in both seasons. A statistically significant difference was observed for temperature, pH, O_2 concentration, nitrate concentration, and total nitrogen. The results of the physico-chemical analysis of water from Šator Lake are in accordance with the [17]. Based on the obtained values for oxygen saturation (%) and the referenced Decision, the water from Šator Lake in both seasons shows a high ecological potential. However, the values for total phosphorus and nitrogen exceed the reference values for moderate ecological potential. Ultimately, the obtained results suggest that the water from Šator Lake exhibits minimal or no anthropogenic alteration.

Based on the obtained results of the morphometric parameters, it can be concluded that *Phoxinellus alepidotus* individuals had greater values of total length, standard length, and weight in autumn compared to spring, while only the value of Fulton's condition factor was higher in spring (Graph 1).

The recorded mean total length of *Phoxinellus alepidotus* individuals in spring was 8.60 ± 0.89 cm, and in autumn 8.86 ± 1.15 cm. The average standard length in spring was 7.18 ± 0.75 cm, and in autumn 7.36 ± 1.06 cm, while the average weight of individuals in spring was 6.30 ± 2.55 g, and in autumn 6.90 ± 3.64 g. The recorded value of Fulton's condition factor was 1.66 ± 0.34 in spring and 1.63 ± 0.32 in autumn. No significant difference was found for any of the analyzed morphometric parameters of *Phoxinellus alepidotus* individuals in relation to the season (Table 2).

Tabe 1. Physicochemical parameters of the water

Parameters	Measuring unit	Spiring ($\bar{X}$)	Autumn ($\bar{X}$)	t - test	p - value
Water temperature	(°C)	16,00	11,93	0,000.	**p<0,05**
pH		8,69	9,27	0,000.	**p<0,05**
O_2 concentration	(mg/l)	11,15	9,20	0,004.	**p<0,05**
O_2 saturation	(%)	134,50	101,03	0,001.	p>0,05
Electrolytic conductivity	(µS /cm)	207,00	209,90	0,791.	p>0,05
Suspended matter	(mg/l)	7,83	6,73	0,248.	p>0,05
Turbidity	(NTU)	2,88	3,78	0,468.	p>0,05
BOD_5	(mg O_2/l)	1,84	2,44	0,935.	p>0,05
COD	(mg O_2/l)	>10	>10	-	-
Nitrates	(mg/l)	1,26	5,18	0,000.	**p<0,05**
Chlorides	(mg/l)	29,67	36,47	0,326.	p>0,05
Fluorides	(mg/l)	0,39	0,32	0,366.	p>0,05
Nitrities	(mg/l)	0,04	0,02	0,240.	p>0,05
Phosphorus	(mg/l)	0,19	0,92	0,427.	p>0,05
Phosphates	(mg/l)	0,61	2,93	0,430.	p>0,05
Ammonia	(mg/l)	0,01	0,02	0,713.	p>0,05
Total nitrogen	(mg/l)	0,05	1,80	0,007.	**p<0,05**
Ash	(mg/l)	17,67	17,67	1	p>0,05
Dry matter	(mg/l)	216,00	195,67	0,759.	p>0,05
Sulphates	(mg/l)	28,59	29,14	0,455.	p>0,05



Graph 1. Morphometric parameters of *Phoxinellus alepidotus*

Table 2. Confidence intervals of the analyzed morphometric parameters of *Phoxinellus alepidotus*

Phoxinellus alepidotus	N	Body mass (g)	Standard length (cm)	Total length (cm)	Fulton's coefficient
Spring $\bar{X}$	20	6,30	7,18	8,60	1,66
Autumn $\bar{X}$	20	6,90	7,36	8,86	1,63
t - test		0,551.	0,528.	0,428.	0,795.
p - value		p>0,05	p>0,05	p>0,05	p>0,05

4. Discussion

Comparing the results of this research with literature data on the length of *Phoxinellus alepidotus*, it is evident that individuals from Šator Lake are smaller compared to the lengths reported for this species in other lake ecosystems. [18] Reported that *Phoxinellus alepidotus* can reach lengths of up to 14.50 cm, [19] noted lengths up to 14 cm, [20] reported an average total length of 9.28 cm for individuals; while the recorded length of *Phoxinellus alepidotus* from Jablaničko Lake ranged between 90–93 mm [21]. Based on the results obtained in this study, it is evident that individuals from Šator Lake were smaller compared to these reported values. The type of water body significantly affects morphometric parameters. [22] Hypothesized that fish living in smaller aquatic ecosystems, such as smaller rivers, tend to be smaller than fish inhabiting larger water bodies like lakes. This hypothesis was confirmed in this study, as *Phoxinellus alepidotus* individuals from Šator Lake were larger in both seasons compared to those from the sinkhole Korana, whose recorded length was 82.20 mm [23]. Many authors have reported seasonal fluctuations in fish morphometric parameters [4, 24, 25], which was also confirmed in this study, given that *Phoxinellus alepidotus* individuals from Šator Lake were longer and heavier in autumn compared to spring. In their research, [4] reported that individuals of the genus *Pseudophoxinus* are longer in spring than in autumn, which contrasts with the results of this study. Specifically, *Phoxinellus alepidotus* is a species that prefers animal-based food; however, during summer, due to increased water temperature and greater food availability, individuals actively grow, which resulted in *Phoxinellus alepidotus* having greater length and weight in autumn. [26] States that uniformity of conditions in aquatic ecosystems throughout the year is very important when it comes to food availability. Since temperature affects freshwater ecosystems and food availability, it is evident that seasonal climate changes force fish to adapt their diet to environmental conditions, which naturally influences their morphometric parameters. Additionally, during the summer period, fish prepare for winter, so metabolism slows down in autumn as energy is conserved for the winter period. [26] In his research, highlights that Fulton's condition factor values are linked to the spawning phase, noting that this parameter tends to be slightly higher before and during spawning. Given that *Phoxinellus alepidotus* individuals from Šator Lake showed higher Fulton's condition factor values in spring, it can be concluded that the analyzed

population was in the spawning phase. [27] Reported that morphometric characteristics of aquatic organisms are phenotypically plastic and can be seasonally influenced by physical environmental factors during spawning. Since spawning is an exhausting process accompanied by loss of energy and mass in fish, this is also one reason why the analyzed *Phoxinellus alepidotus* population from Šator Lake was longer and heavier in autumn compared to spring. [28] Emphasize that oxygen availability, temperature, and altitude can affect the altered morphology of cyprinids. Considering that the presence of *Phoxinellus alepidotus* in Šator Lake was recorded at the highest altitude, it is evident that specific ecological factors played a very important role regarding morphometric parameters. In their research, [29] highlighted that temperature has a significant and primary influence on fish physiology, growth, and reproduction, and the water temperature in Šator Lake is limited by the high altitude. Finally, it is important to emphasize that the *Phoxinellus alepidotus* population in Šator Lake faces a very specific adaptation, which is the absence of migration into underground waters [14], which is also another reason why this population exhibits smaller morphometric parameter values compared to other studies.

5. Conclusion

Based on the results obtained in this study, seasonal variation in the morphometric parameters of the *Phoxinellus alepidotus* population from Šator Lake was confirmed, influenced by specific ecological factors within this ecosystem. The impact of ecological factors such as altitude and temperature on the morphometric parameters of *Phoxinellus alepidotus* individuals from Šator Lake was observed. Additionally, the influence of food availability and spawning on the morphometric parameter values of *Phoxinellus alepidotus* from Šator Lake was evident, as well as the absence of migration of this species into underground waters during the winter period.

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The Importance of Academic English in Scientific Research

Ratko Knezevic[1], Bozana Tomic[2], Saltanat Meiramova[3] and Natalia Shevchuk[4]

[1] University of Bihac, Bosnia and Herzegovina
[2] Slobomir P University, Bosnia and Herzegovina
[3]A. K. Kussayinov Eurasian Humanities Institute, Astana, Kazakhstan
[4]National Technical University of Ukraine,"Igor Sikorsky Kyiv, Ukraine

E-mail: kratko1962@gmail.com

Abstract: Academic English is the dominant language of scientific research, serving as a bridge for global scholarly communication, peer-reviewed publishing, and interdisciplinary collaboration. This paper examines the role of Academic English in enhancing research visibility, facilitating knowledge dissemination, and improving professional growth. It highlights the challenges faced by non-native English-speaking researchers (NNESRs), including language barriers, limited access to academic writing training, and implicit biases in the publishing process. Strategies such as academic writing programs, AI-based writing tools, and international research collaborations are discussed. Case studies from diverse fields—including medicine, engineering, social sciences, climate science, and artificial intelligence—illustrate the real-world impact of Academic English on research productivity and success. The findings indicate that English proficiency is indispensable for researchers seeking to contribute meaningfully to the global scientific community.

Keywords: Academic English, scientific research, scholarly communication, peer-reviewed publishing, non-native researchers, global collaboration, knowledge dissemination

1. Introduction

1.1 Background and Context

Scientific research is a global endeavour that relies on effective communication to advance knowledge, develop new technologies, and address societal challenges. Historically, scientific discoveries were recorded and shared in multiple languages, including Latin, German, and French. However, over the past century, English has become the dominant language of science, establishing itself as the lingua franca for scholarly publishing, conferences, and academic discourse.

The prevalence of English in scientific research is evident in major academic databases such as Web of Science, Scopus, and Google Scholar, where the vast majority of high-impact research articles are published in English. According to Hyland (2015),

over 98% of research papers in leading scientific journals are written in English, despite the fact that only about 20% of the global population speaks English as a first language.

This linguistic shift has created both opportunities and challenges. While the use of a single language facilitates international collaboration and knowledge dissemination, it also poses significant barriers for non-native English-speaking researchers (NNESRs). Many talented scientists face difficulties in publishing their work due to language-related obstacles, which can slow down the progress of global research.

1.2. The Role of English in Global Scientific Communication

The transition to English as the primary language of science has been driven by several historical and institutional factors:

- The rise of American and British research institutions in the 20th century positioned English as the dominant academic language.
- International funding agencies, such as the National Science Foundation (NSF) and the European Research Council (ERC), require grant applications to be written in English.
- Major scientific conferences use English as the standard language for presentations and publications.
- Global indexing databases, such as PubMed and IEEE Xplore, predominantly feature English-language research, increasing the visibility and impact of English publications.

These factors have made English proficiency essential for researchers seeking academic recognition, funding, and career advancement.

1.3. Challenges Faced by Non-Native English-Speaking Researchers (NNESRs)

Despite its benefits, the dominance of English in academia creates barriers for researchers who do not have strong English proficiency. Some of the key challenges faced by NNESRs include:

- Difficulty in mastering academic writing conventions**.** Scientific writing requires precision, clarity, and adherence to specific formatting guidelines, which can be challenging for NNESRs.
- Limited vocabulary and technical jargon**.** Many researchers struggle to express complex ideas due to limited exposure to specialized English terminology.
- Implicit bias in peer review**.** Studies show that reviewers may reject or criticize papers based on language quality rather than the strength of the research itself (Gómez et al., 2021).
- Increased time and effort required for manuscript preparation**.** NNESRs often spend additional time revising and editing their work, sometimes requiring professional proofreading services.

These challenges can lead to a lower acceptance rate for publications from NNESRs, limiting their ability to contribute to global scientific discussions.

2. The Role of Academic English in Scientific Research

2.1. Standardization and Clarity in Scientific Communication

One of the key advantages of using English as the global language of science is the standardization of academic communication. Standardized language use ensures that scientific knowledge is easily accessible, reducing misunderstandings caused by linguistic differences.

For example, disciplines such as medicine and engineering require precise terminology to describe procedures, experimental results, and technical specifications. A lack of standardization could lead to misinterpretations, potentially affecting patient care, engineering safety, and technological development.

2.2. The Impact of English on Research Visibility and Citation Rates

Studies indicate that English-language research articles receive significantly more citations than those published in other languages. Lillis and Curry (2010) found that English-language publications have a citation rate 2–3 times higher than non-English publications in many fields. The primary reasons for this advantage include:

- Inclusion in major databases**.** English-language journals are more likely to be indexed in Scopus, Web of Science, and other high-impact databases.
- Wider readership**.** Since most researchers engage with English-language literature, papers published in English reach a larger audience.
- Higher chance of being referenced in future research**.** English-language studies are more frequently cited in new academic papers, increasing their impact factor.

This citation disparity affects the academic careers of NNESRs, as citation counts are often used as a metric for career progression, funding decisions, and institutional rankings.

2.3. The Importance of English in Interdisciplinary Research and Collaboration

Modern scientific research increasingly involves interdisciplinary collaboration, requiring researchers from diverse fields to communicate effectively. English facilitates collaboration across disciplines by providing a shared medium for:

- Multinational research teams working on complex projects, such as climate change modelling, artificial intelligence development, and space exploration.
- Cross-disciplinary conferences where researchers from different backgrounds share insights and methodologies.

- Industry-academia partnerships, particularly in fields such as biotechnology, renewable energy, and healthcare.

For example, the Human Genome Project, a global initiative that mapped human DNA, relied on English as the working language for international teams. Without a common linguistic framework, coordination across research centres in different countries would have been significantly more difficult.

3. Linguistic Challenges in Scientific Research

3.1. Complexity of Academic Writing in English

Scientific writing in English follows strict conventions regarding structure, tone, and argumentation. Many NNESRs struggle with:

- Grammar and syntax errors**.** Common issues include incorrect verb tense usage, awkward sentence structures, and article misuse.
- Lack of familiarity with academic style**.** Many NNESRs find it difficult to balance formal writing with clarity and conciseness.
- Challenges in organizing research papers**.** The standard IMRAD format (Introduction, Methods, Results, and Discussion) requires logical flow and coherence, which can be difficult for those unfamiliar with English writing conventions.

These challenges often result in multiple revisions, leading to delays in publication and increased workload for researchers.

3.2. Cultural and Rhetorical Differences in Writing

Different languages have unique rhetorical structures, which can make it challenging for NNESRs to adapt to English academic writing. For example:

- In some languages, indirect argumentation is preferred**,** while English academic writing prioritizes direct and clear arguments.
- Certain languages use long, complex sentences**,** whereas English emphasizes clarity and brevity.
- The use of passive voice differs across languages**.** English scientific writing often favours the passive voice in specific contexts, but excessive use can make texts difficult to read.

Researchers who are not accustomed to these stylistic conventions may struggle to make their work align with English academic standards.

3.3. The Psychological and Cognitive Burden of Writing in a Second Language

Writing in a second language requires additional cognitive effort. NNESRs often experience:

- Longer writing and editing times due to the need for careful word choice and revision.
- Increased anxiety over potential language errors that might affect the credibility of their work.
- Frustration with rejection rates if journals criticize their writing quality rather than the scientific content.

The psychological pressure associated with writing in English can discourage researchers from submitting their work to international journals, reducing the diversity of voices in global academia.

4. Barriers to Publishing for Non-Native English-Speaking Researchers (NNESRs)

4.1. Rejection Rates and Editorial Bias in Scientific Journals

One of the major challenges faced by NNESRs is the higher rejection rate of their manuscripts due to language quality rather than the scientific merit of their research. Several studies indicate that journal editors and peer reviewers may unconsciously favour well-written submissions over those with linguistic flaws, even if the research findings are equally significant.

Case Study: The Impact of Language on Peer Review Outcomes

A study by Flowerdew (2015) analysed the peer review process for NNESRs submitting to high-impact English-language journals. The findings revealed that:

- 35% of rejected papers cited poor language quality as a primary reason for rejection.
- 25% of NNESRs had their manuscripts returned with a request for extensive language editing before resubmission.
- Only 10% of native English-speaking researchers (NESRs) faced similar language-related revisions.

This bias creates an uneven playing field, as NNESRs must invest additional time and financial resources in professional editing services to meet journal standards.

4.2. The Cost of Professional Language Editing Services

Many researchers from non-English-speaking backgrounds rely on professional academic editors to improve the readability of their manuscripts. However, this solution is not always accessible due to financial constraints, particularly for researchers in developing countries.

The average cost of language editing services can range from $150 to $500 per manuscript, depending on the complexity and word count. For researchers working on multiple publications or applying for grants, these costs can become a significant financial burden.

Some universities and research institutions provide internal language editing support, but these services are often limited to high-ranking faculty members, leaving early-career researchers without adequate assistance.

Potential Solutions:

- University-supported writing centres**.** Institutions can establish academic writing centres that offer free or subsidized language assistance to researchers.
- Collaborations with native English-speaking researchers**.** Encouraging cross-border collaboration can help NNESRs improve their academic writing through mentorship.
- AI-powered writing tools**.** Technologies such as Grammarly, Writefull, and Trinka AI can assist researchers in refining their academic writing skills at a lower cost.

4.3. Limited Access to High-Quality Academic English Training

Unlike their native English-speaking counterparts, many NNESRs do not have formal training in academic writing. While some universities offer English for Academic Purposes (EAP) courses, access to these programs varies widely across institutions and countries.

In a survey conducted by Lillis & Curry (2010), 65% of NNESRs reported feeling underprepared for academic writing in English, while 40% stated that their institutions offered little to no formal training in scientific English writing.

Case Study: English for Academic Purposes (EAP) Programs in Europe vs. Asia

- European universities, particularly in Nordic countries, have integrated EAP courses into graduate-level education, ensuring that students develop strong writing skills before engaging in research.
- Asian universities, particularly in China and Japan, offer fewer structured EAP programs, resulting in researchers relying on self-study or external language coaching.

Expanding access to formalized academic English training at the undergraduate and graduate levels could significantly reduce the language barrier in scientific publishing.

5. Strategies to Support NNESRs in Academic Publishing

5.1. Institutional and Government Initiatives

To bridge the language gap in scientific research, universities and funding agencies must implement policies that support NNESRs.

Key Initiatives:

1. Language Support Grants**:** Some international organizations, such as the European Union's Horizon program, provide grants to cover language editing costs for researchers from non-English-speaking countries.
2. University Writing Centres**:** Institutions can establish dedicated writing centres that offer academic English training, peer review assistance, and editing support.
3. International Writing Collaboration Programs**:** Universities can facilitate writing partnerships between NNESRs and NESRs to improve the quality of scientific manuscripts.

5.2. The Role of Artificial Intelligence (AI) in Language Assistance
Advancements in AI have led to the development of tools that can assist researchers in overcoming language barriers. AI-powered language tools such as:

- Grammarly (grammar and style improvement),
- Writefull (context-specific academic writing suggestions), and
- DeepL Translator (accurate translations with academic tone)

are increasingly being used to refine academic manuscripts.

A study by Cao & Xiao (2022) found that researchers who used AI-based language tools experienced:

- 40% reduction in grammatical errors,
- 25% faster manuscript preparation time, and
- 30% increase in acceptance rates in international journals.

While AI cannot replace human editing entirely, it provides a cost-effective way for NNESRs to improve their writing before submitting to journals.

5.3. Encouraging Multilingualism in Academic Publishing
Although English is the dominant language of science, some initiatives aim to promote multilingualism in research publishing. Journals such as *PLoS ONE* and *Elsevier's Global Translations Initiative* have started offering bilingual abstracts and translated versions of selected articles.

These efforts ensure that research findings are accessible to non-English-speaking audiences while maintaining the global reach of English-language publications.

6. Conclusion

The dominance of English in scientific research has enabled greater international collaboration, knowledge dissemination, and academic standardization. However, it has also created significant challenges for NNESRs, who face higher rejection rates, financial burdens for language editing, and limited access to academic writing training.

To ensure a more inclusive research environment, academic institutions, funding agencies, and publishers must take proactive steps to:

1. Expand access to academic English training programs at universities worldwide.
2. Provide financial support for language editing services to level the playing field for NNESRs.
3. Leverage AI-powered language tools to assist researchers in refining their manuscripts.
4. Encourage multilingual publication initiatives to increase the accessibility of research findings across linguistic communities.

By addressing these challenges, the scientific community can create a more equitable and diverse research landscape, where knowledge is not restricted by linguistic barriers but is accessible to all.

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Understanding the Role of Processing Conditions in Cold Pressed Milk Thistle Oil Quality

Sebila Rekanović, Halid Makić, Elvisa Hodžić, Samira Dedić, Anita Vuković

Biotechnical Faculty of the University of Bihać, Bosnia and Herzegovina

E-mail: sebilarekanovic@outlook.com

Abstract. Silybum Marianum L. is a medicinal plant that has been used for the treatment of various diseases such as liver, and gall bladder disorders since the ancient times. The largest amounts of active ingredients are obtained from the plants seeds. The seeds contain approximately 70 – 80 % of silymarin (herbal medicine based on silymarin fruit) and 20 – 30 % of a chemically undefined fraction consisting of polymeric and oxidized polyphenols. In the production of silymarin, milk thistle oil is a by-product, however, due to the various useful ingredients in preventing different diseases and promoting health, cold pressed milk thistle seed oil is increasingly being produced and used. The aim of this work was to examine the quality of oil obtained from the milk thistle seeds, by changing the process parameters in the technological process of cold pressing. The process of pressing the seeds was carried out on a continuous screw press. By pressing the seeds, three products were obtained: crude oil, oil residue, and cake. During pressing, the process parameters were changed: the frequency of the electric motor (speed of the auger), the temperature of the press head and the attachment for the cake exit. After the cold pressing of the seeds, the basic parameters of oil quality were examined: peroxide number, iodine number, free fatty acid content, moisture content and insoluble impurities. The results demonstrated that the process parameters significantly influence the oils yield and quality. Adjustments to the pressing conditions, such as temperature and auger speed, had a measurable impact on the oxidative stability, chemical composition, and purity of the oil. Optimizing these parameters is essential to maximize oil quality while maintaining the health-promoting properties of milk thistle oil, making it a valuable product in the functional food and nutraceutical industries.

1. Introduction

Oils from non-traditional seeds such as safflower, silymarin and black cumin are becoming increasingly popular and receiving more attention and research in recent years. Due to its extremely good nutritional values, it is of significant interest to consumers who use it as a culinary product, but also because of its impact on diseases and raising awareness of health through a diet that includes a high concentration of

monounsaturated and polyunsaturated fatty acids and antioxidant phenolic compounds [1,2].

Milk thistle (*Silybum marianum L.*) is an autochthonous annual or biennial herbaceous plant. Its fruits and seeds are used as an herbal treatment for liver and biliary tract problems. The content of its seeds has antioxidant, antiatherosclerosis, antihypertensive, antiobesity, antidiabetic, anti-inflammatory and anticancer properties. Although milk thistle was most often used for the extraction of silymarin, nowadays cold-pressed oil is increasingly being produced. As a by-product of the industrial production of silymarin, milk thistle seed oil is an extremely important product. Cold-pressed vegetable oils are a source of energy for the human body, and they are produced by a mechanical pressing process without heating in order to preserve the nutritional value and quality. Due to their chemical composition, especially essential fatty acids, such as linoleic and oleic acids, which are beneficial to human health by reducing arteriosclerosis, diabetes and cancer, they are important for maintaining health and preventing diseases [2,3,4,5].

The main factors affecting the extraction efficiency and oil quality are the seed pretreatment and the oil extraction method. There are two types of vegetable oil extraction: the conventional type (organic solvent extraction, hot and cold pressing) and the new type of extraction (supercritical CO_2 extraction, ultrasound and microwave extraction, pulsed electric field extraction, etc.). New extraction methods allow for higher oil yields, reduced solvent consumption and shortened extraction time.

All possible vegetable oil extraction methods have some advantages and disadvantages; therefore, the oil yield, cost-effectiveness and recycling of the extraction solvent, as well as the obtained oil quality, must be taken into account [5,6,7,8]. Cold pressing of oil is a simple, cost-effective and safe (for consumers and the environment) extraction method that can provide very pure, safe and nutritionally rich oil. Although it is a low-energy method that preserves most of the bioactive compounds, its disadvantages include limited yield [7,8,9].

In this study, the objective was to investigate the influence of pressing process parameters on the efficiency of cold-pressed milk thistle seed oil production. The pressing was performed using a laboratory-scale continuous screw press. During the process, the heating temperature of the press head was systematically varied, while the frequency of the screw's electric motor was kept constant and monitored.

The pressing resulted in three primary products: crude oil, oil sediment (residue), and press cake (pomace). Following the pressing, the volume and temperature of the crude oil were measured, along with the mass of the press cake. The crude oil was subsequently subjected to sedimentation and vacuum filtration in order to separate the oil from residual solid matter, yielding the final cold-pressed oil. In addition, standard analytical methods were used to determine key quality parameters of the milk thistle seed oil, including peroxide value, free fatty acid content, moisture content (dry matter in oil), and saponification value.

2. Materials and methods

For the production of cold-pressed oil, cleaned, dried and unshelled milk thistle seeds were used. The oil pressing was carried out in the laboratory of the Faculty of Biotechnology on the continuous screw press shown in Figure 1 (processing capacity 20 kg/h, electric motor power 1.5 kW).

Figure 1. Technological process of obtaining cold-pressed milk thistle oil.

Figure 2. Milk thistle flower, seed, oil and pomace.

After pressing, crude oil, oil residue and cake were obtained (Figure 2). The crude oil naturally settled for 14 days, at room temperature and in a dark place.

2.1 Methods of determining oil quality parameters

2.1.1 Peroxide number determination (PNo)

The peroxide number is an indicator of the freshness or rancidity of a fat or oil. In the further stage of deterioration, peroxides, i.e. hydroperoxides break down and produce aldehydes, ketones, alcohols, acids, etc., which are the carriers of the unpleasant smell and taste of the oil. The peroxide value of the tested oil was determined by the standard method (BAS EN ISO 3960). In short, the oil sample was dissolved in a mixture of glacial acetic acid and chloroform, mixed, and added potassium iodide solution. The action of peroxide leads to the release of iodine from the potassium iodide solution, which is then determined by titration with sodium thiosulfate.

2.1.2 Determination of free fatty acids (FFA)

Fats and oils, along with triacylglycerols, also contain a certain amount of free fatty acids. The action of lipolytic enzymes on the ester bond in the triacylglycerol molecule leads to hydrolytic decomposition and the formation of a certain proportion of free fatty acids that increase the acidity of the oil. The proportion of free fatty acids in the oil depends on the raw material used, the method of obtaining and storage conditions (Regulation on methods of analysis of olive oil, Official Gazette of BiH 68/80, 2013).

2.1.3 Determination of moisture in oil

The presence of moisture in the oil is considered an impurity, and under certain conditions, the proportion of free fatty acids may increase, which leads to an increase in acidity and deterioration of the oil quality. Larger amounts of moisture can cause the oil to become cloudy and thereby impair the aesthetic appearance and make it unacceptable. Determination of the amount of moisture and volatile substances in the oil is based on the evaporation of water and volatile substances from the oil by heating in a dryer at a temperature of 103 ± 2 °C. After drying, it is cooled down to room temperature in a desiccator and the sample is weighed (BAS EN ISO 662).

2.1.4 Determination of saponification number

The saponification number indicates the number of mg of KOH required for complete saponification of free and ester bound fatty acids. The value of the saponification number is a characteristic constant for individual oils or fats and depends on the molecular masses of the fatty acids that make up the fat. The value of the saponification number is higher if the molecular weight is lower and vice versa. In addition, the content of the saponification number is also affected by the content of unsaponifiable matter. Saponification of fats and oils is carried out using an alcoholic solution of KOH, of known molarity, and the excess of unbound hydroxides is retreated with a solution of hydrochloric acid (HCl) of known molarity (Regulations on methods of analysis of olive oil, Official Gazette of BiH 68/80, 2013).

3. Results and Discussion

This study investigated the influence of pressing temperature on the quality parameters and oil yield from cold-pressed oil production. While the pressing gap (N = 15 mm) and frequency (F = 22 Hz) were held constant, the pressing temperature was varied from 85 °C to 110 °C (with an average value 97.5 ±9.35) to examine its effects on both oil characteristics and process efficiency.

Table 1 shows that with sample number 6, when the temperature was increased to 110°C, a larger amount of cold-pressed oil (final product) of 153 mL was produced. The lowest yield of the final product was in sample 1 where the temperature was 80°C. Further determination revealed the proportion of pomace in sample 1 (589.90 g) and the lowest in sample 2 (556.58 g), (with an average value 568.83±11.26).

Table 1. The influence of pressing process parameters on oil utilization.

SAMPLES	PRESSING PARAMETERS			CRUDE AND COLD PRESSED OIL			
	N (mm)	T (°C)	F (Hz)	Mass of starting crude material (g)	Temp. of crude oil (°C)	Volume of crude oil (mL)	Pomace mass (g)
1	15	85	22	700.52	30	73	589.90
2	15	90	22	700.16	35	75	556.58
3	15	95	22	700.31	35	80	569.03
4	15	100	22	700.11	37	80	563.11
5	15	105	22	700.45	36	83	566.16
6	15	110	22	700.34	39	85	568.22
$\bar{x}\pm\sigma$		**97.5 ±9.35**		**700.31± 0.15**	**35± 3.33**	**79.33± 4.58**	**568.83± 11.26**

The results obtained and shown in tables 1 and 2 show the influence of process parameters on the pressing of seeds, as well as the quality parameters of cold-pressed oils. The results showed that the oil extraction yield after cold pressing extraction without seed treatment was the lowest in sample 1 (10.42%) and the highest in sample 6 (21.84%), depending on the temperature of the cochlea.

The oil yield showed a positive linear correlation with pressing temperature, increasing from 9.59% at 85 °C to 11.17% at 110 °C. This trend is attributed to the temperature-enhanced fluidity of the oil and decreased viscosity, which facilitate better oil release from the seed matrix. The increase in oil volume with temperature was accompanied by a corresponding decrease in tropa mass, suggesting more efficient oil extraction.

The highest yield was observed at 110 °C, indicating that elevated temperatures improve mechanical extraction efficiency. However, such benefits must be balanced with potential changes in oil quality.

The percentage of dry matter in oil increased with temperature, peaking at 95–100 °C, then decreased. This could reflect more effective mechanical disruption at mid-range temperatures, leading to increased transfer of fine solids into the oil phase, followed by partial sedimentation or degradation at higher temperatures.

Table 2. Basic quality parameters of cold-pressed silymarin oil.

SAMPLES	PRESSING PARAMETERS			QUALITY PARAMETERS				
	N (mm)	T (°C)	F (Hz)	Free fatty acids (FFA), %	Peroxide number (PNo), mmol 0_2/kg	Saponification number SN (mg KOH/1 g)	Dry matter content in oil (%)	Dry matter content in pomace (%)
1	15	85	22	2.88	4.67	6.294	1.584	0.332
2	15	90	22	4.12	2.37	3.036	2.296	0.332
3	15	95	22	3.69	3.30	6.175	2.424	0.350
4	15	100	22	4.14	2.47	6.350	2.397	0.303
5	15	105	22	4.05	4.41	3.926	2.228	0.344
6	15	110	22	3.80	0.68	3.990	1.885	0.326

Free fatty acid content increased with temperature up to 100 °C (from 2.88% to 4.14%) and then slightly declined at 110 °C (3.78±047). The initial rise may result from enhanced enzymatic or thermal hydrolysis of triacylglycerols. However, the subsequent decrease at the highest temperature could indicate thermal deactivation of hydrolytic enzymes or lower water content, limiting hydrolysis.

Although elevated temperatures typically accelerate lipid oxidation, the observed decrease in peroxide value at 110 °C (0.68 mmol O_2/kg) is likely due to specific characteristics of the cold pressing process. Notably, the exposure time of oil to high temperature is short, and the oxygen availability is limited due to the enclosed, continuous operation of the press. These conditions reduce the opportunity for oxygen to initiate peroxidation. Moreover, at higher temperatures, there may be thermal deactivation of oxidative enzymes such as lipoxygenases, which otherwise contribute to hydroperoxide formation at lower temperatures. The reduced moisture content at 110 °C could further limit hydrolytic and oxidative degradation, as water often facilitates radical formation.

Similar findings were reported by Torres and Maestri [15], and Okparanta et al. [16], who observed that oil oxidation parameters do not always follow a linear relationship with temperature, especially in low-oxygen or short-exposure environments. In such cases, moderate thermal treatment may improve oil stability by disrupting enzymatic pathways or facilitating separation of pro-oxidant impurities. Moreover, Frankel [17] explained that peroxide value typically reaches a maximum and subsequently declines as hydroperoxides decompose into secondary oxidation products.

The phenomenon of low peroxide value at high temperatures may seem counterintuitive, there are several mechanisms that explain this process. Hydroperoxides, which are the primary products of lipid oxidation, are very unstable and easily degraded. At higher temperatures, the rate of this decomposition increases, which can result in a decrease in the peroxide value, despite the initial increase during the initial oxidation phase. High temperatures can inactivate enzymes such as lipoxygenase, which catalyze the initial stages of lipid oxidation. Without the activity of these enzymes, the process of hydroperoxide formation is slowed or stopped, which can result in low peroxide values. If the oxidation system is isolated from additional oxygen, the availability of oxygen is limited, which reduces the rate of hydroperoxide formation.

The saponification value fluctuated, with high values at 85, 95, and 100 °C. A peak at 100 °C (6.350 mg KOH/g) may indicate higher proportions of shorter-chain fatty acids. Lower values at 90 and 105 °C suggest potential degradation or volatilization of some lipid components.

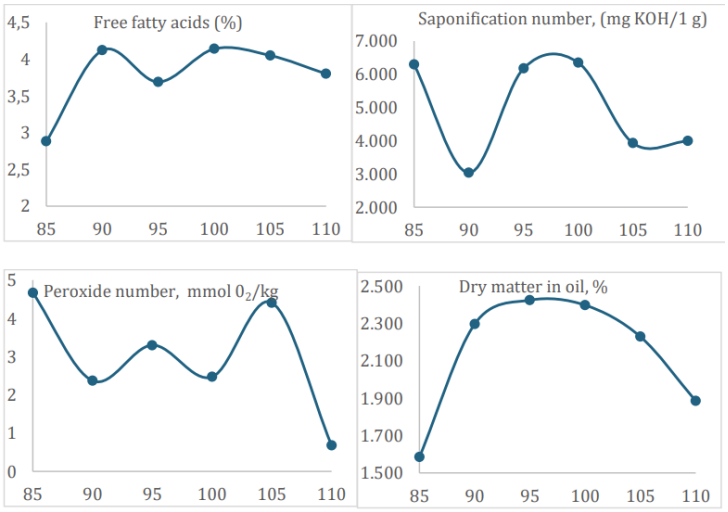

Figure 3. Quality parameters of cold-pressed milk thistle oil.

The moisture content results in more sediments in the oil and causes more frictional resistance, which results in a higher pressing speed. Choking/jamming of seeds or cake occurs with lower seed moisture content. Conversely, a higher moisture content increases plasticity, which reduces the level of compression and contributes to poor oil utilization.

The yield of oil extraction from the seeds was quite low because the intact cell wall caused great resistance to oil extraction not only when using cold pressing but also when using solvents [8]. The content of oil is highly dependent on low temperatures, salinity and water stress during the plant growing season [9,10].

The obtained results had similar values compared to the research by Moslavac et al. [11,12]; Martinez et al. [13,14] who found that changing the temperature of the press head heater affects the production of oil, and increasing the temperature of the press head heater, the volume of the obtained final cold-pressed oil also increases with the reduction of residual oil in the cake. In the aforementioned research, as the temperature of the press head heater increases, so does the amount of oil obtained. As the temperature increases, the process pressure increases and the viscosity of the oil decreases, which results in greater oil draining and thus greater oil utilization during pressing.

Such a conclusion also coincides with this research, because by increasing the temperature of the press head, a larger amount of oil is produced, so the most oil was obtained at a temperature of 115 °C.

Okparanta et al. [15] showed that moisture content has both increasing and decreasing effects on quality parameters (saponification value, iodine, free fatty acids and colour). The authors also observed that increasing moisture content affects the colour of the oil, which changes from brown to dark brown. Torres and Maestri [16] also reported that the colour intensity of palm kernel and sesame oils increases with

increasing moisture content. In general, peroxide number measures the extent to which rancidity reactions have occurred during storage, which is used as an indicator of the quality and stability of fats and oils [18,19,21]. Acid value is a measure of oil degradation degree caused by lipases or other, which is accelerated by light and heat [19,22]. Oxidative and chemical changes in oils during storage are characterized by an increase in free fatty acid content and a decrease in the total unsaturation of the oil [19,20,23,24]. The obtained values of the mentioned quality parameters are in accordance with the Rulebook on edible vegetable oils, edible vegetable fats and mayonnaise (Official Gazette of Bosnia and Herzegovina, 21/37, 2011).

4. Conclusions

The results of this study highlight the significant role of pressing temperature in influencing both the quantity and quality of cold-pressed oil. Oil yield improved consistently with rising temperatures, peaking at 110 °C. Oil quality parameters showed more complex, non-linear responses, with optimal values for some characteristics (like low peroxide value and stable saponification number) also observed at higher temperatures.

The pressing temperature range of 100–105 °C appears to offer a balance between high yield and favourable quality, though 110 °C yields the most stable and abundant oil under the studied conditions.

These findings support the optimization of pressing conditions in small-scale or artisanal cold-pressed oil production, where balancing efficiency and product quality is crucial. Further work could explore the impact of these parameters on sensory attributes, shelf life, and fatty acid composition to complete the quality profile.

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The impact of feeding laying hens on blood lipid profile

Suzana Jahić

University of Bihać, Biotechnical Faculty, Bosnia and Herzegovina

E-mail: suzana.jahic@unbi.ba

Abstract. An experiment was performed so that a total number of 96 laying hens Isa Brown were divided into four equal groups, eight replicate, and in each replicate of four hens. There were three experimental groups in whose basal diet it was added garlic powder in different concentrations (2%, 4%, 6%) and control group that received diet with no addition of garlic powder. Diet and drinking water were provided ad libitum during the experimental period. All hens belonged to the same age group of 28 weeks. They were fed designed meals over a period of 4 weeks. In this experiment examined the effect of adding garlic powder to a standard feed mixture on the cholesterol content and triglyceride content in the blood serum of laying hens. The serum cholesterol content of the laying hens increased, with addition of the garlic powder in the standard fodder mixture, compared to the control group, with a statistically significant increase ($p<0.05$) in the group with 4% and 6% of garlic powder; the same parameters were within the normal limits of content. The serum triglyceride level decreased with the addition of garlic powder, with a statistically significant reduction ($p<0.05$) with hens that had received 6% addition of garlic powder in the standard fodder mixture, where a reduction of 54.57% compared to control group was obtained by the group of 6% addition of garlic powder.

1. Introduction

The World Health Organization nowadays encourages the use of natural phytogenic substances to replace or reduce the use of antibiotic growth promoters. As feed additives for the improvement of health and performances of animals, breeders use plant derivatives called phytobiotics (1). Garlic (*Allium sativum*) is a perennial bulb-producing plant that belongs to the genus *Allium* in the family *Liliaceae* (2). It has a specific smell and taste, as well as therapeutic properties in alternative medicine (3) and it has been used as a feed additive since ancient times (2). Garlic (*Allium sativum*) is known for its flavoring effects on food and herbal effects on various diseases (4,5). Garlic has bioactive components like sulfur containing compounds (alliin, diallylsulfides and allicin) that act as antibacterial, antifungal, antiviral, antioxidant, antithrombotic,

ant cancerous and vasodilator characteristics (6). Garlic has been found to inhibit bacterial growth ([7), inhibit platelet growth and reduce oxidative stress (6). In broilers, it was reported that garlic, as a natural feed additive, improved broiler growth and feed conversion ratio, and decreased mortality rate (8).

Garlic could be given to poultry in the form of powder, aqueous extract, essential oil, and other commercial products either in the feed or in the drinking water. Supplementation of garlic in feeding of poultry resulted in enhancement in growth performance, gut health, dressing yield, and production cost [9, 10, 11). Garlic participates in modulation of immunity and blood parameters [12] and prevention of bacterial and parasitic infections [13, 14). The addition of garlic to the broilers' feed has no negative influence because it does not leave any residue, and the birds' manure does not contaminate the environment. Therefore, products from garlic-consuming animals are safe for consumption (15).

2. Material and methods

2.1 Feeding od laying hens

Table 1. is shows the composition of the feed mixture for feeding laying hens; dehydrated garlic powder used in the feed mixture for feeding laying hens consists of: 12.80% protein, 3.75% fat, 5.05% ash, and 5.00% water.

Table 1. Composition of the feed mixture for feeding laying hens (share in % of the total feed mixture) control and experiment

Composition of feed mixture%	Control group	Experimental groups		
	0 % GP	2% GP	4% GP	6% GP
Corn	58.36	56.36	54.36	52.36
Soybean meal, 44% SP	26.31	26.31	26.31	36.31
Fodder chalk	8.19	8.19	8.19	8.19
Dehydrated alfalfa	2.92	2.92	2.92	2.92
Sunflower oil	2.92	2.92	2.92	2.92
Sodium chloride	0.3	0.3	0.3	0.3
Garlic powder	0	2	4	6
Vitamin-mineral premix*	1	1	1	1
TOTAL	100	100	100	100
Calculated nutritional ingredients				
Metabolic energy (kcal ME/kg)	2311.86	2253.94	2196.02	2138.1
Crude protein%	18.14	18.19	18.23	18.29
Crude fiber %	5.46	5.36	5.26	5.16
Ether extract%	4.95	4.79	4.63	4.47
Ca %	3.1	3.1	3.1	3.09
Total phosphorus%	0.44	0.47	0.46	0.45
methionine %	0.24	0.24	0.24	0.24
lysine %	0.96	0.96	0.95	0.94

[a] 1 kg of vitamin-mineral premix contains 960,000 IU of vitamin A, 200, 000 IU of vitamin D3, 2, 000 IU of vitamin E, 160 mg of vitamin K3, 800 mg of Ca - D -pentathenate, 2,000 mg of nicotinic acid 360 mg of vitamin B6, 1,600 mg of vitamin B12, 4,000 mcg of biotin, 3,200 mg of zinc, 4,800 mg manganese, 1,200 mg of copper, 120 mg of iodine, 24 mg of cobalt, 30 mg of selenium, 420 mg of canthaxanthin, and 36,000 FTU of 6 phytase. 0% GP - control group (no supplement of garlic powder), 2% GP - 2% share of garlic powder in the feed mixture, 4% GP – 4% share of garlic powder in the feed mixture, 6% GP – 6% share of powder in the feed mix.

Laying hens were fed on a private farm in the municipality of Bosanska Krupa, Una-Sana Canton, Bosnia and Herzegovina. Garlic powder was purchased from the company Kolmix d.o.o., Municipality of Velika Kladuša, Una-Sana Canton, Bosnia and Herzegovina. Laying hens of the "Isa-Brown" breed aged 28 weeks were divided into three experimental groups and a control group. They were fed designed meals over a period of 4 weeks. Hens were divided into three groups of 32 laying hens in each experimental group (cage breeding) plus a control group of 32 laying hens. Each group consists of 8 replicates, with 4 laying hens in each replicate, for a total of 96 laying hens. Garlic powder in concentrations of 2%, 4%, and 6% was added to the standard mixture for feeding laying hens. In the control group of laying hens, no garlic was added to the feed mixture. Water and food are provided ad libitum. Light period: 16 hours; dark period: 8 hours.

2.2. Determination of blood lipid profile

At the end of the experimental period of feeding, blood serum samples were taken using the random sampling method; 4 samples each from each of the three experimental groups of laying hens and 4 samples from the control group. Blood was taken from the ving vein using sterile needles, and blood samples were placed in 4 ml test tubes. The blood was allowed to stand at room temperature for 45 minutes to separate the serum; we analyzed the cholesterol and triglyceride content in blood serum using the spectrophotometric method (16) on a spectrophotometric analyzer (LP 420, Germany), with the BioSystems cholesterol reagent. For the detection of cholesterol content, we used a spectrophotometer filter with a wavelength of 520 nm, and for the triglyceride content, a filter with a wavelength of 546 nm.

2.3. Statistical data processing

Statistical data processing and we used the method of descriptive analysis for statistical data processing. We calculated the arithmetic mean, variance, standard deviation and coefficient of variation (17). Significance level was $\alpha=0.05$ - $*p<0.05$ – statistically significant difference between groups; $**p<0.01$ – highly statistically significant difference between groups, $p>0.05$, NS – no statistically significant difference between groups. We tested the results by applying the appropriate variance analysis model, analysis of variance with one factor of variability between the control group (the group that took the standard feed mixture) and the experimental groups (groups with the addition of garlic powder in the feed mixture in concentrations of 2%, 4%, 6%).

3. Results and discussion

Table 2. shows the results of cholesterol and triglyceride content in blood serum.

Table 2. Content of cholesterol and triglyceride (mg/dl) in blood serum of laying hens

Parameter	0% GP		2% GP		4% GP		6% GP		
	x±SD	CV	x±SD	CV	x±SD	CV	x±SD	CV	F
Cholesterol content (mg/dl)	78.77 ±6.197	0.079	100.72 ±36.265	0.360	157.55 ±45,22	0.288	144.31 ±17.475	0.121	5.835*
Triglyceride content (mg/dl)	976.49 ±264.001	0.271	931.68 ±367.842	0.395	934.78 ±180.988	0.194	434.98 ±185.499	0.427	3.881*

[a] 0% GP - control group (no supplement of garlic powder), 2% GP - 2% share of garlic powder in the feed mixture, 4% GP - 4% share of garlic powder in the feed mixture, 6% GP - 6% share of powder in the feed mixture.[b] x- average value, SD – standard deviation, CV - coefficient of variation, F value - value of Fisher's test, *statistical significance (p<0.05).

Since it was determined that there was a statistically significant difference (p<0.05) between the samples, the Tukey test was used to determine which groups had a statistically significant difference (p<0.05). Table 3. shows the results of the Tukey test for comparing cholesterol content (mg/dl) in the blood serum of laying hens.

Table 3. Comparison by Tukey test for serum cholesterol content (mg/dl) – control and all three experimental groups; significance level α = 0.05

Comparison	Difference	Standardized difference	Critical value	p-value	Statistically significant
4% : 0%	78.778	3.652	2.969	0.015	yes
4% : 2%	56.836	2.635	2.969	0.088	no
4% : 6%	13.243	0.614	2.969	0.926	no
6% : 0%	65,535	3.038	2.969	0.044	yes
6% : 2%	43.594	2.021	2.969	0.234	no
2% : 0%	21.942	1.017	2.969	0.743	no
Critical value of Tukey test:			*T = 4.199*		

[a]0% GP - control group (no supplement of garlic powder), 2% GP - 2% share of garlic powder in the feed mixture, 4% GP - 4% share of garlic powder in the feed mixture, 6% GP - 6% share of powder in the feed mixture.

Table 4. shows the results of the Tukey test for comparing triglyceride content (mg/dl) in the blood serum of laying hens.

There is no statistically significant difference (p>0.05) between the control group and the experimental groups with 2% and 4% of garlic powder in the feed mixture for the content of triglycerides in the blood serum of laying hens, while there is a statistically significant difference (p<0.05) for the content of triglycerides in the blood serum of laying hens between the control group and the experimental group with 6% of the garlic powder in the feed mixture. The level of cholesterol in the blood serum of laying hens increased with the increasing the proportion of garlic powder in the standard feed mixture (Table 2). A statistically significant difference (p<0.05) was

observed in the garlic powder supplement group of 4% (157.55 mg/dl) and a statistically significant difference ($p<0.05$) in the garlic powder supplement group of 6% (144.31 mg/dl) compared to the control group (78.77 mg/dl).

Table 4. Comparison by Tukey test for serum trigliceryde content (mg/dl) – control and all three experimental groups; significance level $\alpha = 0.05$

Comparison	Difference	Standardized difference	Critical value	p-value	Statistically significant
4% : 0%	540.514	2.930	2.969	0.053	no
4% : 2%	43.808	0.238	2.969	0.995	no
4% : 6%	40,710	0.221	2.969	0.996	no
6% : 0%	499.804	2.710	2.969	0.078	no
6% : 2%	3.097	0.017	2.969	1.000	no
2% : 0%	496.706	2.693	2.969	0.080	no
Critical value of Tukey test:			*T = 4.199*		

[a]0% GP - control group (no supplement of garlic powder), 2% GP - 2% share of garlic powder in the feed mixture, 4% GP - 4% share of garlic powder in the feed mixture, 6% GP - 6% share of powder in the feed mixture.

A statistically significant difference ($p<0.05$) was determined for the triglyceride content (mg/dl) for all four groups by one-factor analysis of variance, we made a comparison of each experimental group with the control group (Table 5).

Table 5. Individual comparison by Tukey test for serum triglyceride content (mg/dl) – control and each of the three experimental groups; significance level $\alpha = 0.05$

Comparison	Difference	Standardized difference	Critical value	p-value	Statistically significant
0% : 2%	43.808	0.194	2.448	0.853	no
0% : 4%	40.710	0.254	2.448	0.808	no
0% : 6%	540.514	3.350	2.448	0.015	yes
Critical value of Tukey test:			*T = 3.461*		

[a]0% GP - control group (no supplement of garlic powder), 2% GP - 2% share of garlic powder in the feed mixture, 4% GP - 4% share of garlic powder in the feed mixture, 6% GP - 6% share of powder in the feed mixture.

The increase in cholesterol concentration in the serum of laying hens was not statistically significant ($p>0.05$), in the group that took the supplement of 2% garlic powder (100.72 mg/dl) in the standard feed mixture compared to the control group. Kaya and Macit (18) report that there was no significant effect on the cholesterol and triglyceride content in the serum of laying hens that received 2%, 4%, 6% and 8% garlic powder with 200 ppm copper in a standard feed mixture.

According to Motamedi and Tahlini (19), the addition of 3% garlic powder to the standard feed mixture had no effect on the cholesterol content in the serum of laying hens, while Ao et al. (20) stated that the addition of fermented garlic powder to the standard feed mixture reduced the cholesterol content in the blood serum of laying hens. According to Khan at al. (21) 2%, 6% and 8% garlic powder reduced serum cholesterol concentrations on average ower 6 weeks by 20.6%, 38.12% and 50.62% respectively.

The level of triglycerides in the blood serum of laying hens decreased with the addition of garlic powder to the standard feed mixture; in the control group, the highest value was observed of 976.49 mg/dl, in the group with 2% supplementation of garlic powder 931.68 mg/dl, in the group with 4% supplementation of garlic powder 934.78 mg/dl and in the group with 6% supplementation of garlic powder, the triglyceride content was the lowest 434.98 mg/dl (Table 2). A statistically significant decrease ($p<0.05$) in the triglyceride content was observed in the experimental group with 6% of garlic powder in the standard feed mixture, (Table 5). Ghasemi et al. (22) obtained that the level of triglycerides in the serum decreased with an the percentage of the herbal mixture (garlic and thyme 1:1) increasing in the standard feed mixture. The content of triglycerides decreased in the blood serum of laying hens according to Azeka et al. (23) whit supplementation of garlic powder in concentrations of 10 and 20 g/kg to the standard feed mixture.

4. Conclusion

The addition of garlic powder in a concentration of 2% to the standard feed mixture did not significantly increase the level of cholesterol content in the blood serum of laying hens. Higher concentrations of garlic powder (4% and 6%) caused a significant increasing the content of total cholesterol in the blood serum of laying hens, but the mentioned parameters are within the limits of normal values. The level of triglycerides in the blood serum of laying hens decreased with the addition of garlic powder to the standard feed mixture of laying hens. The lowest value of triglyceride content was recorded in the experimental group with the addition of 6% garlic powder, which represents a reduction of 54.58% compared to the control group.

The supplementation of garlic to layer hens shows improvement in important blood parameters. Further researches should be focused on finding the optimal concentration of garlic powder in poultry diets without compromising bird health or product quality.

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Methane as a product of ruminant metabolism and its impact on the environment

Husein Vilic and Refik Sahinovic

University of Bihac, Biotechnical Faculty, Bosnia and Herzegovina

E-mail: husein.vilic@unbi.ba

Abstract. Agriculture accounts for about 47%-56% of total anthropogenic methane (CH_4) emissions. It is known that within the agricultural sector, ruminant livestock (dairy, beef, goats and sheep) significantly contributes to the increase in CH_4 production through the continuous natural process of rumen fermentation. In order to reduce the effects caused by global warming caused by greenhouse gases, especially methane, it is necessary to change livestock production systems and adopt new strategic approaches. Reducing enteric methane in livestock farming is a long-standing problem of energy efficiency of animal feed consumption. This review investigates the sources of production, spread, and introduction of accepted scientific and practical solutions to reduce methane gas in dairy cattle breeding and production units. Methane emissions are now the second largest contributor to global warming, with an impact 23 times greater than that of carbon dioxide (CO_2). Many factors influence the amount of CH_4 production in ruminants, including feed intake, feed type and quality, energy expenditure, animal size, growth rate, production rate, and ambient temperature. Methane is also produced from animal manure depending on the physical form of the feces, the amount of digestible material, climate, and the length of time it has been unused. The majority of methanogenesis in ruminants occurs in a large fermentation chamber called the rumen. The anaerobic digestion of feed by microorganisms results in the production of acetate, propionate, and butyrate (volatile fatty acids) that the animals use as an energy source, as well as the production of ruminal gases such as carbon dioxide (CO_2) and methane (CH_4), which are eliminated by eructation. Therefore, the aim of this review was to present the current state of methane production by ruminants and its implications and impact on climate change and the environment. In order to present this work, a large number of articles published in valid databases between 1982 and 2023 were investigated. A total of 85 articles were reviewed, and after screening, 48 were included in this review.

1. Introduction

Ruminants are primary producers of methane (CH_4). They can produce 250 to 500 liters of methane per day [1]. This level of production results in an estimate of the contribution of livestock to global warming. Many factors influence these methane

emissions from cattle, including the level of feed intake, the type of carbohydrates in the diet, feed processing, etc. Manipulating these factors can reduce methane emissions from cattle.

The rumen digestion of feed by microorganisms, under anaerobic conditions, results in the production of acetate, propionate and butyrate, which the animal uses as an energy source, and the production of carbon dioxide (CO_2) and methane (CH_4), which are eliminated by eructation [2]. All of these gases are produced in the rumen by the process of methanogenesis. This process, in addition to its negative environmental impact, represents a loss of 2-15% of the gross energy intake [3] for the animal, leading to an unproductive use of dietary energy [4]. Techniques to manipulate this process include the elimination of protozoa [5], the use of antibiotics (such as Monensin and bacteriocins such as Nisin) [6], the use of lipid sources [7], organic acids [8] and ionospheres [9], or changes in diet composition [10].

From a global perspective, CH_4 is a particularly major greenhouse gas (GHG) with a global potential 23 times greater than carbon dioxide [11] and accounts for 16% of total global greenhouse gas emissions.

In livestock, most CH_4 is produced by enteric fermentation, a natural process produced by ruminants, which is responsible for one-third of agricultural methane [12]. Enteric methane produced by ruminants originates in the rumen [2]. Globally, atmospheric CH_4 concentrations have increased between pre-industrial times and 2005 from approximately 0.715 ppm to 1.774 ppm [13].

The global atmospheric CH_4 load was 4850 megatons in 1998, equivalent to an average concentration of 1745 ppb [14]. Atmospheric CH_4 concentrations are thought to be increasing at a rate of 22 megatons per year, due to an imbalance between estimated annual global emissions of 598 megatons and removals of 576 megatons [15].

2. Overview of general characteristics of methane

Methane is one of the three main greenhouse gases, along with CO_2 and nitrous oxide (N_2O). Its global warming potential is 23 times that of CO_2 [11]. Methane is a colorless, odorless, flammable, and tasteless gas that is the primary component of natural gas. Methane occurs naturally in the atmosphere; CH_4 is lighter than air and has a specific gravity of 0.554. Methane gas has a density of 0.717 m-3/kg, a melting point of -187 °C, and a boiling point of -161 °C. This gas is insoluble in water, but soluble in organic solvents. CH_4 that occurs in nature is mainly produced by the process of methanogenesis. The reaction is: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ [16].

3. Source of methane from ruminants

Methane from enteric fermentation: According to Dawou [1], enteric CH_4 is a by-product of ruminant digestion produced by methanogenic microorganisms, Archaea, in a

process called fermentation or methanogenesis. The rate and type of fermentation are influenced by animal factors such as chewing, salivation, and digestion kinetics [17].

Cattle produce about 7 and 9 times more CH_4 than sheep and goats, respectively. Enteric CH_4 is produced mainly in the rumen (87% - 90%) and, to a lesser extent (13% - 10%), in the large intestine [18]. The animal releases CH_4 into the atmosphere by exhaling the gas mainly through the mouth and nostrils [13]. Of the CH_4 produced by enteric fermentation in the foregut, 95% is excreted by eructation, and of the CH_4 produced in the hindgut, 89% is excreted through the breath, with only 11% released through the anus. The work of Munoz et al. [20] recorded 3% from the anus (of the total enteric emissions of CH_4 released through the mouth, nostrils and rectum). The breath concentration is variable with a relatively low concentration when the breath comes from the lungs and a higher concentration when the "breath" gases are belched from the anterior abdomen, although the breath from the lungs also contains CH_4 absorbed and inhaled with the air [21]. In a barn or larger room, the concentration will be largely affected by air exchange, but the CH_4 concentration will be the total mixture of CH_4 from breath, belching, and offgassing processes [21].

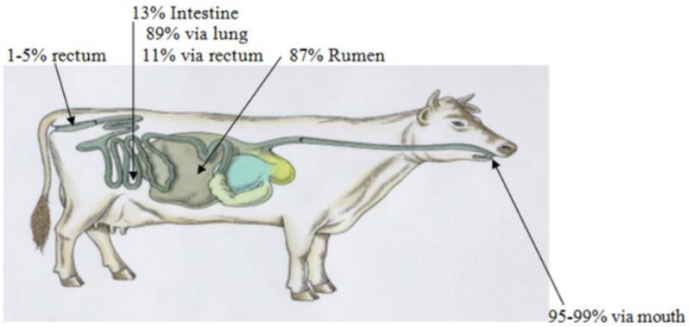

Figure 1. Parts of the cattle body where methane is emitted.

Methane from manure: In addition to enteric CH_4 production, excreta are another source of CH_4, especially when stored aerobically [22]. Methane produced from ruminant and non-ruminant manures contributes 2% and 0.4% of global CH_4 and GHG emissions, respectively. In low-intake regions, enteric fermentation is undoubtedly the main source of emissions. However, in industrialized regions with high food production and processing, it is an important source of emissions [23]. Manure CH_4 emissions are a higher proportion of total on-farm CH_4 emissions in intensively managed dairy operations with manure storage systems, and much lower in extensive or grazing operations because they are mostly in an aerobic state [24]. Livestock manure contains a fraction of organic solids such as protein, carbohydrates, and fat that are available as food and energy for the growth of anaerobic bacteria [1].

Obviously, the benefit of methane production can be the energy value of the gas itself, but the production of gas from manure depends mainly on the efficiency of the

operating system for it. The gas yield can be defined as the amount of gas produced per unit of solids decomposed by anaerobic bacteria [25]. Anaerobic digestion is a natural process in which microorganisms consume organic matter in an oxygen-free environment [1].

The result is the production of microbial biomass and GHGs (CO_2 and CH_4). The composition of volatile solids contained in manure affects the anaerobic decomposition of organic matter and the production of CH_4. Volatile solids of manure mainly consist of fatty acids, proteins and carbohydrates, of which fatty acids, proteins and part of carbohydrates are readily biodegradable [26].

4. CH_4 measurement methods in dairy cows

Respiratory calorimetry (closed or open circuit), polyethylene tunnel systems, isotopic dilution, tracer gas (such as sulfur hexafluoride (SF_6) and micrometeorological mass balance are the most commonly used methods to estimate CH_4 production in ruminants [27]. In addition, new technologies are being developed to measure the amount of CH_4 produced during feeding in robotic milking stations or pasture feeders, or by using rumen sensors [28] to monitor CH_4 concentrations hourly [29].

Also, researchers have used mathematical and experimental models to predict CH_4 production from dairy cows in some studies, and the correlation between digestibility and CH_4 production in their findings has led to a new strategy to address this problem [30]. However, comparison of CH_4 production data obtained by in vitro and in vivo methods has not shown a high correlation. As mentioned, different methods have been used to measure CH_4 in ruminants. However, an appropriate method should have low operating costs, good accuracy, high reproducibility and there is no need for special equipment; it should also measure all CH_4 produced by different means (mouth, nose and anus).

Figure 2. Open circuit chambers.

5. Existing solutions to reduce CH_4 emissions

5.1 Ruminal microbial population

Complex plant carbohydrates are converted into energy due to the evolution of ruminants and microbes, which is beneficial for the host animal and the microbial symbiosis. Bacteria, protozoa, fungi and archaea are rumen microbes.

Unlike other anaerobic ecosystems (such as wetlands and estuaries), the rumen ecosystem rapidly breaks down plant materials as an anaerobic environment and various fermentation products are produced.

Amino acids and soluble proteins are rapidly fermented by microbes in the rumen, resulting in the production of gases such as hydrogen, ammonia and carbon dioxide.

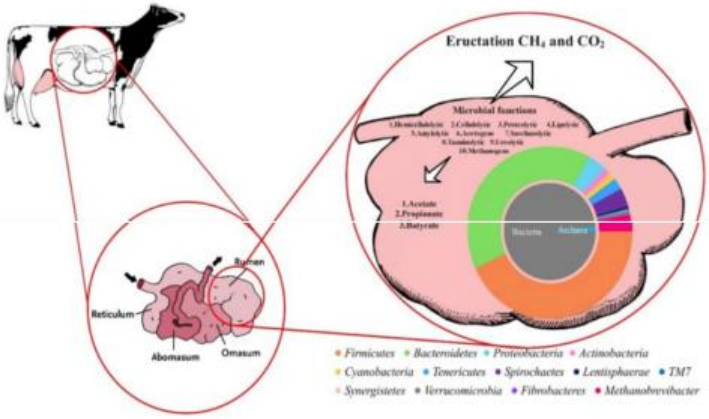

Figure 3. Identified microbial and archaeal populations associated with CH_4 emissions in dairy cows (adapted from [31]).

At the bacterial community type level, CH_4 production is dominated by Firmicutes and Bacteroidetes, with a relative average of more than 83%. Also, Methanobrevibacter and Euryarchaeota play a significant role in CH_4 release at the archaeal level. At the bacterial family level, the most abundant family is Provetella with an average relative abundance of 54%. Other genera such as Succiniclasticum and Ruminococcus are involved in the subsequent stages of CH_4 emission.

5.2 Diet Type

The type of feed allowed to a ruminant can have a major impact on methane production. The ratio of forage to concentrate in the diet has an impact on rumen fermentation and thus on the ratio of acetate to propionate [1]. Therefore, one would expect that methane production would be lower when fed a high-concentrate diet [32]. According to Van Soest [33], a diet rich in grains and/or the addition of soluble carbohydrates resulted in a shift in the rumen fermentation pattern that created a more hostile environment for

methanogenic bacteria in which the passage rate increased, the pH in the rumen was lowered, and certain populations of protozoa, ruminal ciliates, and methanogenic bacteria could be eliminated or inhibited. The work of Lane et al. [34] supports this theory by confirming that low rumen pH regulates CH_4 production.

5.3 Forage Type and Supplementation

Supplementing feed with either low or high quality energy and protein supplements has been well documented to increase the growth efficiency and digestibility of microbes [12]. As a result, milk and meat production will increase. The direct effect on methanogenesis is still variable and unclear, but indirectly, methane production per unit of product will decrease. Increasing the level of non-structural carbohydrates in the diet (by 25%) would reduce CH_4 production by as much as 20%, but this can result in other adverse effects including acidosis, laminitis and fertility problems [1]. In addition, many other factors affect CH_4 production such as season, age of the animal, animal management and rumen protozoa population.

5.4 Vaccination

Another potential strategy that has so far shown contradictory results is vaccination against rumen methanogens. In order to neutralize methanogens, this strategy is based on the creation of antibody responses that are transmitted to the rumen by salivary secretions.

Many producers would find it simple to administer this vaccination as they already follow annual vaccination protocols. Consequently, compared to alternative techniques, vaccination could be more expensive [35]. It was found that the concentration of avian anti-methanogenic antibodies (IgY) can reduce the production of CH_4 in vitro [36].

In vivo vaccination trials, however promising, may be limited by our current knowledge of rumen methanogenic populations. Additionally, in some studies, the use of vaccination not only reduced CH_4, but also slightly increased it [37]. Furthermore, given that each vaccine formulation is unique to the diet and environment, existing research cannot cover the entire range [38,37]. On the other hand, most rumen methanogens are difficult to produce, and most species have not yet been isolated [39]. Since methanogen populations can vary widely depending on region and diet, it is crucial to successfully grow high-yielding methanogenic species in production systems to make vaccination approaches effective in the future [38].

As mentioned, rumen microbial population control strategies, feeding, and vaccination have been proposed as strategies for controlling CH_4 production, and each of them needs further investigation. For example, by controlling the physical and chemical characteristics of the diet, the population of methanogenic archaea in the rumen can be controlled; or by changing the animal diet to a diet containing starch and grains and increasing the amount of lipid in the diet, CH_4 production can be reduced. On the other hand, feed additives such as algae can suppress methanogens and act as an electron acceptor. Vaccination is also receiving much attention today, but its results are

contradictory and require further investigation. All of these strategies may be effective, but the side effects of each of them, the cost, public access, and the amount of CH_4 reduction in each method need to be evaluated. In order to increase the effectiveness of these methods, the possibility of their simultaneous use should also be assessed.

6. Advantages and disadvantages of CH_4 mitigation methods

Addition of fat is considered a strategy to increase the energy level of ruminant diets [40]. Also, improved reproduction has been reported with additional sources of fat, possibly due to improved energy balance as well as the effects of fatty acids on hormones that play a vital role in reproduction [41]. Perhaps the most important drawback of this method is the limitation of its amount in the rations of dairy cows due to negative effects on fiber digestion in the rumen [42].

One of the most important advantages of carrying out vaccination is the ease of use for farmers, because they use a kind of annual vaccination protocol. Also, vaccination can be cost-effective [35] and induce strong antibodies in ruminants [43]. On the other hand, most species of methanogens are difficult to cultivate in vitro, which is one of the disadvantages of this method [39].

Improving pasture quality can improve feed digestibility and lead to a reduction in intestinal CH_4 emissions [44,45,46]. Flavonoids, tannins, pectin, glycosides, terpenoids and sesquiterpene lactones are known as the most important plant secondary metabolites. Some of these compounds are toxic to the animal or act as inhibitors through the sense of taste [47]. However, some of these compounds show promise for improving animal productivity and health and reducing intestinal CH_4 production. The most important compounds are saponins, concentrated tannins and essential oils [45]. The percentage composition of gases does not depend on the type of food ingested, but it changes considerably during individual stages of digestion, i.e. depending on the time elapsed after feeding [48].

7. Conclusions

Among livestock, ruminants are the primary producers of CH_4. They can produce 250 to 500 liters of methane per day. In general, animal management is an important contributor to global greenhouse gas emissions, especially CH_4. This review has summarized the current state of knowledge on only some of the environmental aspects of methane production. Reducing methane production in ruminants is a difficult issue. However, progress can be made towards reducing methane production from biotechnology, by increasing animal efficiency, producing high-quality forages and pastures, using alternative forages and concentrates that are high in ingredients such as tannin and saponin, and by using probiotics.

Dairy cows have a high multifunctional value in livestock and agriculture, which should be considered in terms of sustainable dairy industry research and production

development in developing countries. CH_4 emissions can be reduced by improving the quality of the feed by adding more cool-season forages and legumes and by rotating grazing animals, including forages with beneficial secondary compounds such as dense tannins and saponins, which also have the potential to reduce CH_4. Providing dietary supplements that improve the nutritional status of livestock and the energy efficiency of feed has the potential to reduce CH_4 emissions from grazing livestock. Strategies to reduce CH_4 in grazing environments are limited, but producer decisions that improve animal nutritional status, forage quality, and supplementation with compounds known to reduce CH_4 can reduce CH_4 production. Now that less expensive and easier-to-use tools are available, researchers should conduct longer-term monitoring experiments and focus on reducing CH_4 production in animals, as the reduction potential is greatest. However, local expertise and capacity can be supported by appropriate research technologies from developed countries to understand the source and extent of greenhouse gas emissions from ruminants in different agricultural and livestock systems.

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Habits and attitudes of respondents towards probiotics

Azira Hrnjica[1], Huska Jukić[1], Elma Beriša[1], Sadat Kurtalić[2] and Samir Porić[1]

[1] Faculty of Health Studies, Bihać, Bosnia and Herzegovina
[2]Department of Internal Medicine, Cantonal Hospital "Dr. Irfan Ljubijankić", Bihać, Bosnia and Herzegovina

E-mail: azira.hrnjica@unbi.ba

Abstract. Probiotics are live microorganisms that, when ingested in sufficient quantities, contribute to maintaining the balance of the gut microbiota, strengthening the immune system, preventing and treating certain diseases, and improving mental health. The aim of the research was to examine the level of awareness, habits and attitudes of consumers towards probiotics, with special emphasis on the forms of probiotics and the reasons for their use. The research was conducted with an online questionnaire on a sample of 122 respondents of different ages and genders. The results showed that awareness of probiotics is very high (98%), and 80% of respondents actively use them. The majority of respondents use probiotics only when necessary, while a smaller number of respondents practice daily use. These results indicate a positive attitude of the general population towards the importance of probiotics in preserving health. This indicates the justification and the need for further education in order to reduce information gaps and increase the use of probiotics in everyday life.

1. Introduction

The beneficial effects of probiotic food on human health have been increasingly recognized by health professionals over time. Scientific studies suggest that probiotics play an important role in immune, digestive, and respiratory functions. Over the past 20 years, research in the field of probiotics has made significant progress, and there has been considerable advancement in the selection and characterization of specific probiotic cultures and substantiating health claims related to their consumption. Bacteria are normal inhabitants of humans, including the gastrointestinal tract, where more than 400 bacterial species are found. Concentration of microorganisms in the large intestine is approximately 10^{12} bacteria/g. Bacterial colonization of the gut begins at birth and continues throughout life, with specific age-related flora changes. Bacteria, which form the resident intestinal microflora, do not have any acute side effects and some of them are necessary to maintain human well-being [1]. Due to all these scientific

knowledge about their well-being, it is recommended to consume probiotic food or take probiotics in the form of nutritional supplements. In today's fast-paced lifestyle, dietary supplements offer a simple way to consume probiotics.

The aim of the research was to determine the reasons for the use of probiotics, a source of information about their health benefits, and the frequency and form of their use. The goal was also to assess the user satisfaction with the effect of probiotics and to point out the potential benefits of their use. The obtained data can serve as a basis for further research and education of consumers about the importance of probiotics in everyday nutrition.

2. Theory

2.1 Development of probiotics, their types and functions

The works of Metchnikoff and Tissier were the first to make scientific proposals regarding the probiotic use of bacteria. The word "probiotic" was coined in 1960 to describe substances produced by microorganisms that promote the growth of other microorganisms. The term probiotic is a relatively new word used to describe bacteria that have beneficial effects on humans and animals.

The first observations of the positive role of selected bacteria are attributed to Eli Metchnikoff, a Russian Nobel Prize winner who claimed that it is possible to replace harmful flora with beneficial microbes in the gastrointestinal tract and that intestinal flora also depends on food [1]. Henry Tissiera isolated *Bifidobacterium* from the intestines of infants and found that the presence of these bacteria reduced the incidence of diarrhea. This discovery led to the idea of the therapeutic use of bifidobacteria for the treatment of gastrointestinal disorders. Minoru Shirota isolated *Lactobacillus casei* in Japan in 1930. Until 1935, Minoru Shirota developed the milk drink "Yakult," claiming that regular consumption improves the digestive system and contributes to longevity. The product has been available on the market since 1935 and is one of the first commercial probiotic products [2]. From the mid-20th century, the focus of research shifted to the medical uses of probiotics. World Health Organization and Food and Agriculture Organization in 2001 developed a definition of probiotics as "living microorganisms which, when used in appropriate amounts, bring a health effect to the host" [3].

There are 86 different types of probiotics, each with different functions. Among the most common types of probiotics are *Lactobacillus acidophilus*, *Lactobacillus rhamnosus*, *Bifidobacterium longum* and *Saccharomyces boulardii*. *Lactobacillus acidophilus* is a bacterium found naturally in the digestive system, urinary tract and other parts of the body. It produces lactic acid from lactose through the enzyme lactase and thus helps create an acidic environment, which prevents the growth of pathogenic bacteria. It occurs naturally in fermented dairy products and naturally fermented foods [4,5]. *Lactobacillus rhamnosus* is part of the normal microbiota in approximately 8% of

humans. This bacterium strengthens the immune system and is used in therapy for treating viral gastroenteritis. It also participates in the production of short-chain fatty acids, restores the intestinal mucosa, reduces the risk of colon cancer and accelerates recovery from allergies. *Bifidobacterium longum* is one of the first bacteria to colonize the sterile digestive system of newborns, and thus plays an important role in the development of their immune system. This bacterium prevents the entry and spread of pathogenic microorganisms, breaks down bile salts, participates in the synthesis of vitamins from group B, and shows anticancer properties. Additionally, it stimulates the immune system through immunoglobulin A, producing acetic and lactic acid that reduce the pH value in the intestines [6]. *Saccharomyces boulardii* is one of the rare probiotic yeasts known for its resistance to gastric acid and bile salts, which enables it to survive in the gastrointestinal tract. It helps maintain the health of the intestinal microflora, especially after the use of antibiotics or chemotherapy. It is used in the prevention and treatment of diarrhea and to prevent the growth of pathogenic microorganisms [7]. Few studies have been published on the beneficial immunomodulatory effects of probiotics. Studies are mainly focused on the metabolic and nutritional properties of probiotics, therefore the mechanisms of interaction between host immune cells and probiotics are only partially described.

One of the mechanisms of immunomodulatory activity is described in a paper by Mazziotta et al. (2023) as the interactive potential of probiotic bacteria with immune cells as well as intestinal epithelial cells. It has been stated that probiotics can improve the immune system of the gut by stimulating B cells to produce IgA. So, taking different probiotics orally, e.g. Lactobacillus casei or Streptococcus thermophilus increases the number of intestinal cells that produce IgA in a dose-dependent manner. Lactobacillus casei and rhamnosus GG have been shown to be effective in stimulating an immune response against rotavirus in children with acute diarrhoea. This probiotic effectiveness in immunomodulating responses against rotavirus has been documented, and currently, a large number of probiotics are recommended for treating diarrhea and other gastrointestinal diseases. In the treatment of these diseases, lactobacilli are currently considered the most effective bacteria [8]. Another important function of probiotics is metabolic function. The microbiota participates in the digestion of complex food molecules, the production of short-chain fatty acids, and the synthesis of vitamins such as vitamin K and B complex [9].

3. Materials and methods

The paper uses scientific methods of description, deductive and inductive methods. The sample method, surveys, statistical method and empirical-non-experimental method were also used. The research was conducted using a survey questionnaire on the perception, attitudes and habits of the respondents in relation to probiotics. The survey questionnaire was created using the online platform "Google Forms". The questionnaire was anonymous and contained a total of 13 open-ended and multiple-choice questions.

The questions included demographic data (age, gender), knowledge of probiotics, reasons for their use or avoidance, frequency of use, satisfaction with the effect of probiotics, and possible obstacles in their use. The target population included adults of various age groups, and a total of 122 participants voluntarily participated in the study. Data collection lasted a week, during which all responses were recorded anonymously. „Microsoft Excel“ was used for additional processing and more detailed data analysis.

4. Results

A total of 122 respondents participated in the research, of which 46% were 15-24 years old, 39% were 24-39 years old, and 15% were 50 years old or older. According to the gender distribution of the respondents, 61% were women and 39% were men. The questionnaire was filled out by respondents from all over Bosnia and Herzegovina. Figure 1 shows the sources of information on probiotics in subjects.

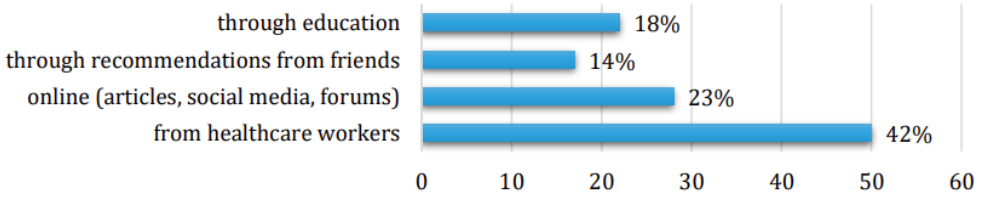

Figure 9. How subjects get information about probiotics

The reasons for which the subjects use probiotics are shown in Figure 2.

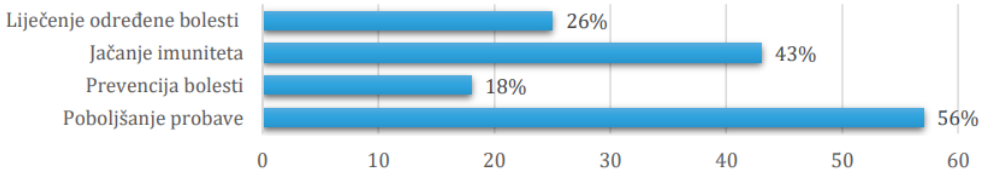

Figure 10. Reasons for using probiotics in the subjects

The form of probiotics most commonly consumed by the subjects is shown in Figure 3.

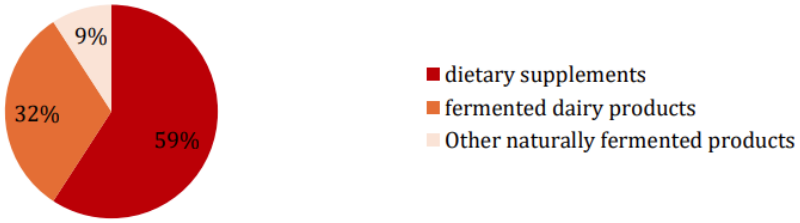

Figure 11. The most commonly consumed forms of probiotics in subjects

The frequency of probiotic consumption in subjects is shown in Figure 4.

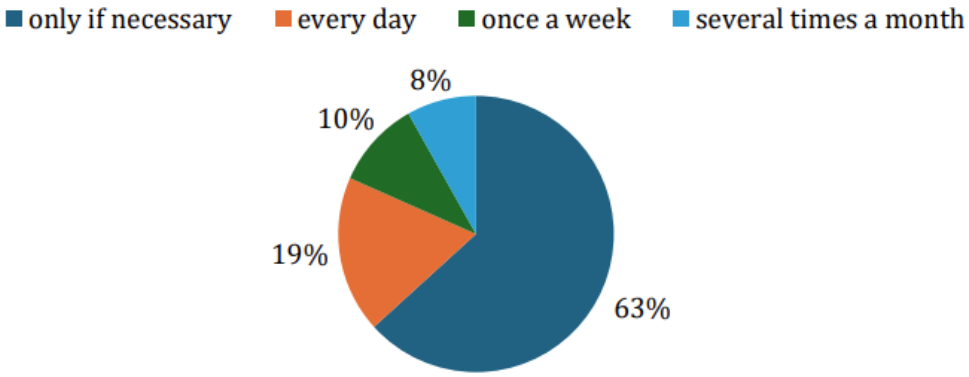

Figure 12. Frequency of probiotic consumption in subjects

81% of respondents agreed that probiotics have a beneficial effect on human health.

5. Discussion

Research results indicate a high level of awareness and use of probiotics among the subjects, confirming that probiotics have become a significant part of dietary and health habits. The age group of respondents shows that the majority of respondents are younger people (15 to 24 years old), which may be a consequence of their greater availability to participate in research or greater interest in the topic. The gender structure shows a higher representation of women in the sample, which may be the

result of their greater interest in participating in the study or their greater focus on health and dietary habits. Internet, as the second most common source of information, is easily accessible and often used, but one must be cautious as it can contain unreliable information and may be subject to marketing bias. Due to the lack of regulation in the probiotic industry, marketing of probiotic products is often directed directly at consumers without any indication of their actual clinical effectiveness. This trend highlights the need to provide adequate indications for the use of probiotics by scientists or clinicians. Different international scientific societies/agencies, such as the *American Gastroenterological Association* (AGA), the *European Society for Paediatric Gastroenterology, Hepatology and Nutrition* (ESPGHAN), and others, they assessed the clinical reliability of probiotics and provided official recommendations for their use in treating gastrointestinal disorders in humans, such as diarrhea, colitis, acute gastroenteritis, irritable bowel syndrome and necrotizing enterocolitis [8]. However, the Internet plays an important role, especially among younger generations, who rely more on digital sources of information. Therefore, it is important to pay attention to the relevance of the information sources available on the Internet and to consider only those that come from medical and scientific professionals. Education enables the acquisition of basic and reliable information about probiotics, their properties and ways of use.

The most common reason for using probiotics among the subjects was to improve digestion, which is in accordance with the literature that confirms the importance of probiotics in preserving the balance of intestinal microflora. The next most common reason for consuming probiotics among the respondents was strengthening the immune system, which further emphasizes the importance of using probiotics for this purpose.

Most respondents use probiotics in the form of dietary supplements, which can be explained by their practicality, ease of use and availability on the market. Dietary supplements often come in the form of capsules, tablets or powders, which enables precise dosing, which makes them suitable for the specific needs of users. Fermented dairy products, such as yogurt and kefir, are used by a significant number of subjects, which indicates the popularity of these foods as a natural source of probiotics. These products are often available in stores and are considered a tasty and healthy option for maintaining a balanced gut microbiota. Naturally fermented products, such as sauerkraut and other traditional fermented foods, are used significantly less. This difference can be explained by the lower availability of these products in today's daily diet, as well as less awareness of their health effects.

The results show that most subjects consume probiotics only as needed. Most often, this can be associated with the use of probiotics during antibiotic therapy. Antibiotics destroy not only pathogenic bacteria, but also beneficial bacteria that are important for maintaining the balance of intestinal microbiota. The use of the targeted sequencing method has shown that antibiotics cause a decrease in the biomass of intestinal

bacteria, their taxonomic diversity and functionality. This often leads to dysbiosis, a condition that can cause symptoms such as diarrhea, bloating, or a general decrease in the body's resistance to infections. Probiotics help restore a healthy gut microbiological composition, reducing the risk of complications and speeding recovery. For these reasons, probiotics are considered useful during and after antibiotic treatment [10].

Miles (2020) conducted a study that showed the effectiveness of the use of supplementation with multi-strain probiotics in athletes in reducing the frequency and severity of gastrointestinal symptoms during training or competition, quantitatively expressed by one third. The interesting thing about this study is that the probability of effectiveness increased with the duration of supplementation. It appears that probiotics taken for at least 11 weeks have shown the greatest effectiveness in reducing the frequency and severity of gastrointestinal symptoms, as well as improving or maintaining the function of the intestinal barrier during training and competition [11].

6. Conclusion

Probiotics have a positive effect on human health; they have protective, immunomodulatory and metabolic functions. To have a positive effect on human health, probiotics must be ingested in the appropriate quantity. It is precisely the ease of taking and dosing that has made probiotics in the form of dietary supplements the most commonly taken form of probiotics. In addition to dietary supplements, good sources of probiotics are fermented dairy products and fermented products. From this study, it can be concluded that Bosnian citizens have a positive attitude towards probiotics and believe in their well-being for health. The most common use of probiotics is mostly only if necessary. However, it has been proven that the effectiveness of probiotics in reducing gastrointestinal symptoms increases with longer supplementation. The Internet is a frequent source of information about probiotics, and therefore it should be considered useful, but also used with caution, that is, only relevant articles written by medical or health professionals should be taken into account.

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Evaluation of the effectiveness of shock wave therapy in patients with painful shoulder syndrome and its impact on extracellular biological effects and tissue regeneration

Sanel Nuspahić, Asmir Aldžić, Alen Lonić and Samir Porić

University of Bihać, Faculty of Health Studies, Bosnia and Herzegovina, Bihać

E-mail: asmir.aldzic@unbi.ba

Abstract. Painful Shoulder Syndrome (Periarthritis Humeroscapularis) is classified as an extra-articular rheumatic condition and represents an acute, subacute, or chronic inflammation of the soft tissues of the shoulder. This painful condition progresses through several stages, lasting from a few months to two years. Painful shoulder syndrome can occur at any time of the year and at any age, though it is more common after the age of forty. The causes of painful shoulder syndrome vary and include pathologies originating from the neck, the glenohumeral joint, the acromioclavicular joint, and the rotator cuff, which accounts for more than two-thirds of cases. The main symptoms include pain in the proximal part of the upper arm, muscle weakness, atrophy, and restricted mobility of the shoulder joint. Shoulder pain is more frequently observed in individuals engaged in certain professions, such as construction workers, hairdressers, waiters, and athletes. Shock wave therapy is a non-invasive method based on the pulsation of mechanical pressure, which propagates as a wave through a special transmission system (applicator) from the targeted painful area through the human body, causing microscopic interstitial and extracellular biological effects, including tissue regeneration. It is defined as a wave with a rapid pressure increase within a very short time, followed by a gradual pressure decrease with a phase of slight negative pressure.

Keywords:
Painful Shoulder Syndrome, Shock wave therapy, tissue

1. Introduction

Periarthritis humeroscapularis, commonly referred to as "painful shoulder syndrome", encompasses a range of distinct painful conditions affecting the shoulder region. It is a frequently encountered diagnosis among the general population and represents a significant health concern, particularly in individuals of both sexes over the age of 40, most often as a consequence of intensive physical activity.

Shoulder pain is more prevalent among individuals engaged in certain professions, such as construction workers, hairdressers, waiters, and athletes. Proper shoulder function is crucial not only during occupational and athletic activities, but also for the

performance of essential daily tasks—including feeding, personal hygiene, and dressing. Therefore, it is vital to promptly identify the underlying cause of shoulder pain and initiate appropriate treatment [1].

Painful shoulder syndrome (periarthritis humeroscapularis, also known as Duplay's disease) is classified as an extra-articular rheumatism and represents an acute, subacute, or chronic inflammation of the soft tissues surrounding the shoulder joint [2]. It is a painful condition that typically progresses through several stages, lasting from a few months up to two years. The primary causes include microtraumas, more significant injuries, exposure to cold, and sudden movements during lifting [2].

The main clinical manifestations include: pain in the proximal part of the upper arm, muscle weakness, atrophy, and restricted range of motion [3]. Patients often report increased pain at night, which interferes with their sleep. The pain typically appears suddenly and may radiate along the lateral aspect of the arm or toward the cervical spine on the same side. Any attempt to move the shoulder joint intensifies the pain and further restricts movement.

The syndrome, as well as its underlying causes, may arise from a broad spectrum of diseases and pathological changes involving the periarticular soft tissues. The etiology is diverse, ranging from infections, rheumatic, vascular, and degenerative diseases, to referred pain originating from abdominal or cervical spine disorders, and even structural alterations of the soft tissues surrounding the shoulder joint. The pathological changes can involve muscles, tendons, ligaments, synovial bursae, the joint capsule, fascia, and other connective tissue structures. The source of the pain may be either intra-articular or extra-articular. Some of these changes are age-related [15].

The aim of this study is to evaluate the effectiveness of shock wave therapy in improving the functional status of patients with painful shoulder syndrome and to analyze its impact on extracellular biological effects and tissue regeneration.

2. Shockwave therapy

Shockwave therapy is a non-invasive method based on the application of mechanical pressure pulses that propagate as waves through a specialized applicator from the targeted painful area into the human body. These waves induce microscopic interstitial and extracellular biological effects, including tissue regeneration. It is defined as a wave characterized by a rapid increase in pressure within a very short time frame, followed by a gradual decrease in pressure and a brief phase of low negative pressure.

Extracorporeally generated high-frequency pressure is focused onto a specific target area. The pressure impulse travels through a liquid medium—typically a coupling gel—and penetrates the patient's soft tissue with minimal energy loss.

Shockwaves are generated by a projectile that is accelerated by compressed air. Through elastic impact, the kinetic energy of the projectile is transferred to the applicator probe and then into the patient's body. Therefore, the applicator must maintain direct contact with the skin and subcutaneous tissue at all times.

Over the past two decades, shockwave therapy has been increasingly employed in physical therapy for the treatment of painful shoulder syndrome, based on principles

originally developed for lithotripsy. Shockwave therapy represents a modern and highly effective method for treating injuries and pain [7, 8].

2.1. Mechanisms of Action of Shockwaves

The mechanical energy of shockwaves is converted into chemical energy within the connective tissue of the extracellular matrix (which comprises all components of the tissue outside the cell itself). Through the involvement of membrane proteins known as integrins (cell surface receptors) and ion channels, this energy is transmitted to the cell nucleus via the cytoskeleton. Within the nucleus, this cascade of signals induces gene transcription and gene expression, ultimately leading to the formation of mechanically sensitive kinases and an increase in collagenase production. This process of biological modulation by shockwaves is known as mechanotransduction.

Fibrocytes are stimulated to produce collagen fibers, which have a stabilizing effect in tendon regions. Mechanotransduction is influenced by the frequency, pressure amplitude, intensity, and duration of the shockwave treatment. This conclusion is derived from clinical observations [9].

Therefore, monitoring clinical progress during shockwave therapy suggests that this modality may be one of the more effective parameters for promoting cellular renewal and regeneration. In everyday clinical practice, it is observed that more frequent impulses, reduced session frequency, longer intervals between treatments, and lower frequencies increase the likelihood of a positive therapeutic outcome.

The primary mechanism of shockwave therapy involves reducing the sensitivity of pain receptors, thereby decreasing overall pain and stimulating the body's natural healing processes, which are often absent in chronic pain conditions.

Numerous theoretical models have been proposed to explain the effects of shockwaves. Clinical experience supports their efficacy, particularly in post-fracture rehabilitation. Shockwaves stimulate the release of osteogenic substances, which are also naturally involved in bone healing. In the treatment of enthesopathies, the beneficial effects of shockwaves can be scientifically validated through the detection of naturally produced biological factors that enhance blood circulation and promote vascularization (the formation of new blood vessels).

Research conducted at seven physical medicine and orthopedic clinics across Germany has confirmed the therapeutic efficacy of both radial and focused shockwave therapy in treating calcific tendinitis of the shoulder. Moreover, focused shockwave therapy demonstrated greater effectiveness than radial waves in reducing the size of calcific deposits [6].

Treatment of patients with calcific tendinitis of the rotator cuff using shockwave therapy has led to radiologically confirmed regression of calcifications. For deeper painful regions within tissues, the use of focused shockwaves is recommended. The more pain trigger points that are identified and treated during a session, the better the treatment outcomes. It is also important to use an adequate amount of ultrasound gel to facilitate effective transmission of shockwaves into the tissue [10].

Shockwaves are directed toward the source of chronic pain, leading to the disintegration of calcium deposits and stimulation of neovascularization at the tendon–

bone interface. This process triggers the early release of angiogenic and other bioactive factors, resulting in improved blood supply and tissue regeneration—an essential physiological process in the treatment of pain and inflammation [5].

Shockwave therapy offers numerous advantages over surgical intervention, such as the absence of postoperative pain, faster recovery of function, elimination of the risk of surgical wound infection, and more rapid return to daily activities [4].

Since pain perception during shockwave therapy varies from patient to patient, it is crucial to determine the optimal dose for each individual and each specific indication [9]. Painful areas and trigger points are localized through palpation in combination with patient communication during treatment.

2.2. Biological Effects of Shockwave Therapy

The biological effects of shockwave therapy are reflected in progress achieved in tissue regeneration in the following areas and through the following outcomes:

- Cellular level**:** increased cell membrane permeability, improved activity of ion channels, stimulation of cell division, stimulation of mobile cytokines;
- Musculoskeletal system**:** enhanced circulation in the musculo-tendinous system, increased concentration of growth factor beta 1;
- Chemotactic and mitogenic effects on osteoblasts**;**
- Improvement of microcirculation and bone metabolism**,** bone tissue remodeling;
- Stimulation of collagen synthesis in tissue**;**
- Stimulation of the central nervous system and regression of pain caused by local ischemia.

3. Research Objectives

a) To analyze the sociodemographic characteristics of patients with shoulder pain syndrome (age, gender).
b) To analyze the effects of shockwave therapy in patients with shoulder pain syndrome.

4. Participants and Research Methods

4.1. Participants

The study included 30 patients diagnosed with shoulder pain syndrome who were treated at MHS – Private Practice for Physical Therapy and Rehabilitation in Sarajevo, during the period from February 3, 2020, to September 4, 2020**.**

4.1.1. Inclusion Criteria

- All patients diagnosed with Periarthritis humeroscapularis treated at MHS – Private Practice for Physical Therapy and Rehabilitation.
- All patients who voluntarily participated in the study and completed questionnaires before and after the therapy sessions.

4.1.2. Exclusion Criteria

- Patients who were not tested at the beginning or end of the therapy.
- Patients who did not complete the treatment.
- Patients who refused to be tested.

5. Research Methods

To assess the condition of the participants before and after the treatment, the DASH questionnaire **–** Disabilities of the Arm, Shoulder, and Hand – was used.

The treatment involved the application of **shockwave therapy** in combination with other procedures of physical medicine. The physical therapy program consisted of 10 sessions conducted over a two-week period**.**

5.1. Research Instrument

The DASH questionnaire (Disabilities of the Arm, Shoulder and Hand) is a 30-item, self-reported questionnaire designed to measure physical function and symptoms in people with musculoskeletal disorders of the upper limbs.

Its purpose is to help describe the disability of individuals with upper extremity disorders and monitor changes in symptoms and function over time.

The version of DASH used at MHS – Private Practice includes scoring for one or two components**:** disability/symptoms (19 items, scored from 1 to 5)**.**

At least 17 out of the 19 questions must be answered in order to calculate a score. The values assigned to the selected responses are summed to yield a final result at admission and discharge**,** on a scale from 0 to 95**.**

- The higher the score, the greater the disability:
  - 0–30**:** good arm function,
  - 31–60**:** satisfactory function,
  - 61–95**:** poor function, disability.

The DASH questionnaire is effective for quick screening, assessment, and monitoring of upper limb function. The estimated time required to complete the questionnaire is 15–20 minutes**.**

6. Research Results

The study included 30 patients who met the inclusion criteria.

Regarding the gender distribution within the examined sample, there were 14 male patients (46.7%) and 16 female patients (53.3%)**.**

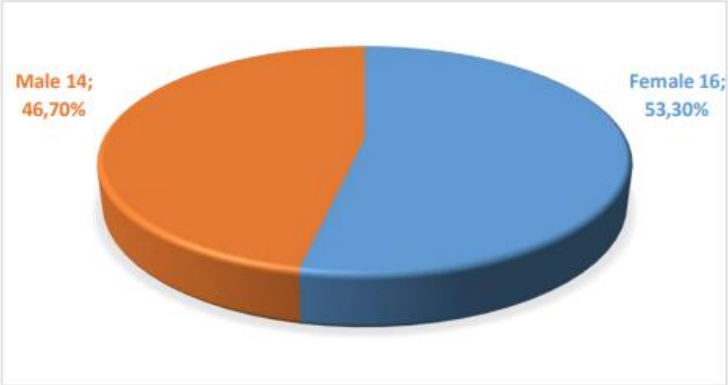

Chart 1. Gender distribution of patients

Application of the chi-square test to the sex distribution of patients revealed no statistically significant difference in gender representation within the examined sample, $\chi^2 = 0.133$; $p = 0.715$.

The largest number of patients belonged to the age group of 60 years and older, totaling 10 individuals (33.3%). The age group 50–59 years included 8 patients (26.7%), the 40–49 years category had 9 patients (30.0%), while only 2 patients (6.7%) were in the 30–39 years category and one patient (3.3%) was in the 18–29 years group.

The frequency distribution of patients across age groups was statistically significant, with a higher number of patients in older age groups compared to younger ones, as confirmed by the chi-square test, $\chi^2 = 11.667$; $p = 0.020$.

6.1. Analysis of the DASH Questionnaire

Analysis of the DASH index scores at admission and discharge revealed that 70% of patients had poor hand function upon admission, whereas only 6.7% had poor function at discharge. Satisfactory hand function was observed in 30% of patients at admission, increasing to 63.3% at discharge. No patients exhibited good hand function at admission, while 30% demonstrated good function at discharge. A statistically significant improvement in scores at discharge was observed ($t = 9.815$; $p = 0.001$).

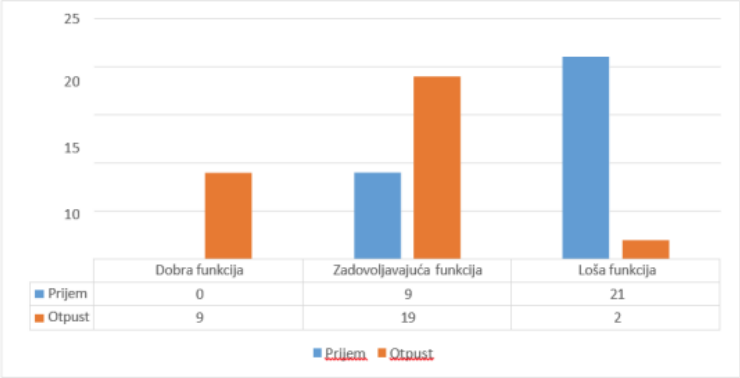

Chart 2. Analysis of DASH Index at Patient Admission and Discharge

Table 1. Mean DASH Index Scores at Admission and Discharge

DASH indeks	N	M	SD	SEM	Minimum	Maximum
Admission	30	61.03	12.187	2.225	32	77
Discharge	30	37.30	11.836	2.161	21	76

	Paired Differences					t	df	P
	X	SD	SEM	95% CI Lower	95% CI Upper			
DASH Admission - Discharge	23.733	10.232	1.868	19.913	27.554	12.705	29	.000

The mean DASH index score at admission was 61.03 ± 12.187, which decreased to 37.30 ± 11.836 at discharge. Application of the paired t-test to the mean scores at admission and discharge revealed a statistically significant improvement of 23.73 ± 10.23 (t = 12.705; p = 0.001).

Table 2. Mean DASH Index Scores at Admission and Discharge by Patient Sex

		N	M	SD	SEM	Minimum	Maximum
Admission	Male	14	58.64	14.468	3.867	32	73
	Female	16	63.13	9.783	2.446	35	77
							F=1.010 p=0.323
Discharge	Male	14	36.86	11.401	3.047	21	61
	Female	16	37.69	12.563	3.141	21	76
							F=0.036 p=0.852

Analysis of mean DASH index scores at admission showed that the average score for male patients was 58.64 ± 14.468, while for female patients it was 63.13 ± 9.783. At discharge, the mean DASH scores were 36.86 ± 11.401 for males and 37.69 ± 12.563 for females.

Application of the ANOVA test revealed no statistically significant difference in mean DASH index scores at admission by sex (F = 1.010; p = 0.323), nor at discharge (F = 0.036; p = 0.852).

The mean DASH index score at admission for patients aged 18–29 years was 32.00, and at discharge it was 23.00. For patients aged 30–39 years, the mean DASH score at admission was 63.50 ± 0.71, and at discharge 40.00 ± 0.00. In the 40–49 age group, the mean DASH score was 59.89 ± 12.04 at admission and 36.22 ± 8.51 at discharge. In the 50–59 age group, the mean admission score was 62.50 ± 11.35, and at discharge 36.00 ± 8.54.

Patients aged 60 years and above had a mean DASH index of 63.30 ± 12.07 at admission, and 40.20 ± 17.15 at discharge.

Table 3. Mean DASH Index Scores at Admission and Discharge by Patient Age Group

DASH Index	(I) DOB	(J) DOB	Mean Difference (I-J)	SEM	P
Admission	18-29	30-39	-31.500	0.500	**0.017**
		40-49	-27.889	4.012	0.059
		50-59	-30.500	4.013	**0.039**
		60+	-31.300	3.815	**0.035**
	30-39	18-29	31.500	0.500	**0.017**
		40-49	3.611	4.012	0.058
		50-59	1.000	4.013	0.908
		60+	0.221	3.815	0.982
	40-49	18-29	27.889	4.012	0.059
		30-39	-3.611	0.500	0.058
		50-59	-2.611	4.013	0.653
		60+	-3.411	3.815	0.546
	50-59	18-29	-30.500	4.013	**0.039**
		30-39	-1.000	0.500	0.908
		40-49	2.611	4.012	0.653
		60+	-0.800	3.815	0.888
	60+	18-29	-31.300	3.815	**0.035**
		30-39	-0.200	0.500	0.982
		40-49	3.411	4.012	0.546
		50-59	0.800	4.013	0.888
Discharge	18-29	30-39	-17.000	0.000	**0.001**
		40-49	-13.222	2.837	0.179
		50-59	-13.000	3.018	0.194
		60+	-17.200	5.422	0.364
	30-39	18-29	17.000	0.000	**0.001**
		40-49	3.778	2.837	0.562
		50-59	4.000	3.018	0.544
		60+	-0.200	5.422	0.988
	40-49	18-29	13.222	2.837	0.179
		30-39	-3.778	0.000	0.562
		50-59	0.222	3.018	0.958
		60+	-3.978	5.422	0.538
	50-59	18-29	13.000	0.000	0.194
		30-39	-4.000	0.000	0.544
		40-49	-0.222	2.837	0.958

At admission, patients in the 18–29 age group had a statistically significantly lower DASH index compared to patients in the 30–39 ($p = 0.017$), 50–59 ($p = 0.039$), and 60+ ($p = 0.035$) age groups.

Application of the t-test to mean DASH index scores at discharge revealed that patients in the 18–29 age group also had a statistically significantly lower DASH index compared to those in the 30–39 age group ($p = 0.001$).

7. Discussion

Shockwave therapy is considered a valuable alternative to surgery due to its effectiveness, safety, and non-invasiveness. The strongest evidence supporting the use of shockwave therapy, as reported by Moya, Ramón et al. (2015), supports the application of low- to medium-energy levels for tendinopathies, and high-energy levels for tendon calcification and bone pathologies, within a comprehensive rehabilitation framework [11].

Our study included 30 participants who met the inclusion criteria. Regarding the sex distribution, the sample consisted of 14 (46.7%) male and 16 (53.3%) female patients. The application of the chi-square test to the sex structure of the sample revealed no statistically significant difference in gender representation ($\chi^2 = 0.133$; $p = 0.715$). Similarly, Singh, Gill et al. (2015) observed that periarthritis was a reported diagnosis in both male and female patients, with humeroscapular periarthritis being the most commonly reported diagnosis in a tertiary care center [12].

In our study, the largest number of patients belonged to the 60+ age group ($n = 10$, 33.3%), followed by the 50–59 age group ($n = 8$, 26.7%), and the 40–49 age group ($n = 9$, 30.0%). Only 2 patients (6.7%) were in the 30–39 age group, and one patient (3.3%) was in the 18–29 group. The frequency distribution of patients by age group was statistically significant, with a greater number of patients in older age groups compared to younger ones, as confirmed by the chi-square test ($\chi^2 = 11.667$; $p = 0.020$). Similarly, a study by Arul Pragassame and Mohandas Kurup conducted at Annamalai University in India found that shoulder periarthritis was most commonly observed in patients aged 46–55 years, highlighting that the dominant shoulder and middle age were common factors in the onset of shoulder periarthritis [13].

In our study, 30% of patients demonstrated satisfactory hand function at admission, which increased to 63.3% at discharge. None of the patients exhibited good hand function at admission, whereas 30% did at discharge.

This indicates a statistically significant improvement in DASH index scores at discharge ($t = 9.815$; $p = 0.001$). In line with this, Moya, Ramón et al. emphasize that with appropriate patient selection, proper indications, standardized therapeutic protocols, and accurate application, shockwave therapy can make a critical contribution to the non-invasive treatment of certain musculoskeletal disorders [11].

Furthermore, the study conducted by Avancini-Dobrović, Schnurrer-Luke Vrbanić, and colleagues at the Center for Physical and Rehabilitation Medicine, University Hospital Centre Rijeka, Croatia, demonstrated statistically significant effectiveness of both radial and focused shockwave therapy in treating calcific tendinitis of the shoulder. They also showed that focused shockwave therapy was more effective than

radial shockwave in reducing calcification size, confirming that shockwave treatment in patients with calcific tendinitis of the rotator cuff leads to statistically significant and radiologically confirmed regression of calcifications [14].

8. Conclusion

Out of a total of 30 participants included in the study, the largest proportion belonged to the age group of 60 years and older (n = 10; 33.3%), and the majority were female (n = 16; 53.3%).

The effectiveness of shock wave therapy in patients with shoulder pain syndrome was evaluated using the DASH index. At admission, 70% of participants exhibited poor upper limb function, while at discharge only 6.7% showed poor function. Satisfactory function was observed in 30% of patients at admission and in 63.3% at discharge. Based on these findings, we conclude that shock wave therapy is highly effective in improving the health status of patients with shoulder pain syndrome.

The assessment of improvement in activities of daily living following shock wave therapy was conducted through the analysis of DASH index results, leading to the conclusion that there was a statistically significant improvement in the health condition of patients with shoulder pain syndrome.

The study confirmed the working hypothesis that daily functioning and shoulder performance are significantly improved in participants who underwent this physiotherapeutic treatment.

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Analysis Of The Sustainability Of A Biogas Plant For The Treatment Of Biodegradable Municipal Waste

Mahmut Jukić and Asmir Aldžić

University of Bihać, Faculty of Health Studies, Bosnia and Herzegovina, Bihać

E-mail: asmir.aldzic@unbi.ba

Abstract. Municipal waste is one of the key challenges of modern civilization, as the increasing amount of waste disrupts the natural balance. The preparation and consumption of food, as well as the maintenance of green public spaces, yards, and gardens, generate biodegradable waste, which constitutes a significant portion of the total municipal waste composition in the Una-Sana Canton. Addressing the issue of biowaste has been recognized as one of the top priorities for reducing environmental pollution and, consequently, for protecting human health, as well as plant and animal life. To maximize the energy potential of municipal waste, biodegradable waste must be separated from other mixed municipal waste at the source. This study focuses on the treatment of biodegradable waste under such conditions.

Keywords: biogas plant, biodegradable waste, sustainability analysis

1. Introduction

The preparation and consumption of food in households and restaurants, as well as the maintenance of green public areas, courtyards and gardens, generates biodegradable waste that needs to be initially separated from the rest of the municipal waste and processed in biological treatment plants, as envisaged in this paper. The basic input data for the dimensioning of such plants are the quantity and composition of municipal waste. In order for the results of the analysis and modelling to be representative, data on quantities must be from official, verified sources, i.e. the Register of Environmental Polluters maintained by the Federal Ministry of Environment and Tourism, and the composition of waste must be determined according to a unified methodology proposed by this ministry.

As a consequence of the aspiration to reduce the impact of the disposal of untreated biodegradable waste, the EU has developed a method of mechanical-biological treatment of municipal waste, i.e. as one of the possibilities of satisfying the EU waste disposal directive, which stipulates that five years after its adoption, the amount of biodegradable organic waste contained in municipal waste must be reduced by 25 percent by weight compared to the state of the reference year. After 8 years, the reduction must be 50 percent by weight, and 15 years after the entry into force of the EU directive, the reduction should be greater than 65 percent by weight.

2. Research Issues

2.1. Method of mechanical-biological treatment of municipal waste

Mechanical-biological treatment of municipal waste includes two key processes, namely mechanical and biological treatment, where different elements of each process can be configured in different ways to achieve a wide range of specific goals, one of the main goals being the production of biogas for the production of heat and/or electricity.
Mechanical treatment of waste separates solid waste fuel (SRF) and recyclable materials, i.e. raw materials from municipal waste, which is then processed by biological treatment.
Biological treatment (bio-drying, biostabilization, composting, anaerobic digestion) is carried out aerobically or anaerobically, including the combined use of one or another method.

This type of waste treatment is used for the treatment of waste with a high biological component (sludge from wastewater, kitchen waste, agricultural waste, etc.). Technological processes of mechanical-biological treatment of municipal waste are shown in Figure 1.

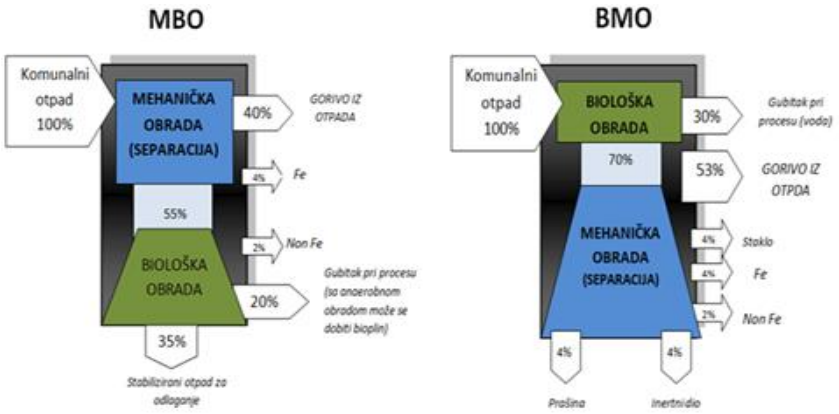

Figure 1. Technological processes of mechanical-biological treatment of municipal waste

2.2. Anaerobni sistemi obrade komunalnog otpada – proizvodnja bioplina

The main product of anaerobic digestion is biogas, which is a mixture of methane, carbon dioxide and other by-products, and is produced as an output product of the anaerobic digestion (AD) process. For this reason, systems in which biogas is produced as the main product within the MBO process are often called "AD-systems".
During the anaerobic digestion process, two products are produced: biogas (methane), which is used to further produce energy, and digestate, which can be in a liquid or solid state. Digestate is not the same as compost unless it is explicitly composted under aerated conditions.

The mass balance of anaerobic digestion is shown in Figure 2.

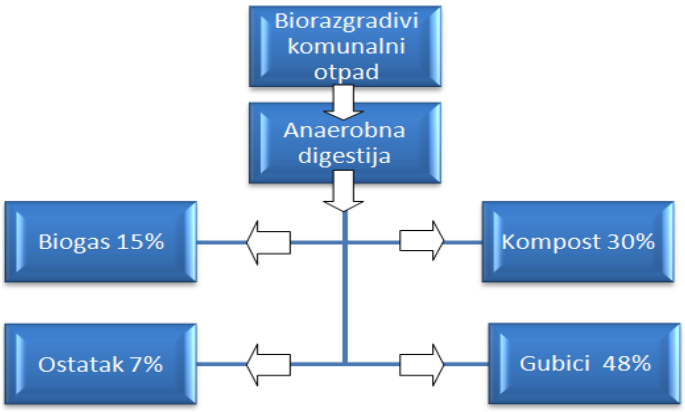

Figure 2. Mass balance of anaerobic digestion

The basic technological conditions for the anaerobic digestion process are the size and type of material, temperature, pressure in the digester, pH value, quality of methane bacteria, oxygen-free atmosphere of the digester, residence time of the substrate in the digester, carbon and nitrogen ratio in the substrate (C/N), mixing of the substrate in the digester and the ratio of dry organic matter to water in the substrate.

There are three types (methods) of anaerobic digestion: dry method, wet method and co-digestion.

Within the dry method, organic waste is crushed and mixed with water before entering the digester with 35% dry matter. The decomposition process takes place at temperatures of 25-55°C and biogas and biomass are obtained. The biogas is purified and used in a gas engine, while the residue after the anaerobic digestion process is disposed of in a landfill.

The wet method involves dumping organic waste into a tank, where it is transformed into a mixture with 12% dry matter. The resulting mixture is first exposed to a temperature of 70° C, at a pH of 10 and then hydrolyzed at 40° C before water is added again. The mixture formed in the second phase of water addition is transformed into biogas and wastewater in a bio-filter through a digestion process. The wastewater can be reused as liquid fertilizer. The fibrous fraction is separated into compost, and the remainder is disposed of in a landfill. The compost usually requires further processing. The purified biogas can be used to produce electricity and heat. Part of the heat energy can be used to maintain a stable temperature during the hydrolysis and bio-filter processes.

In the co-digestion method, which is similar to the wet digestion method, the shredded waste is mixed with sewage sludge or farm manure, in a ratio of 1: 4.

The parameters that differentiate anaerobic digestion plants are: retention time, or the time the digester stays in the digester, which varies from 10 to 25 days, then the moisture content in the digester, based on which there are dry and wet digesters, the process temperature, based on which there are two operating systems in use (thermophilic and mesophilic), and the number of process phases (one or two phases).

The energy efficiency of anaerobic digestion plants with the possibility of combined production of electricity and heat is 30% and 70%, as shown in table 1.

Table 1. Energy efficiency of anaerobic digestion plants

Parameters	Minimum values	Maksimal values
Biogas production	70 m^3/ton of waste	140 m^3/ ton of waste
The proportion of methane	55%	60%
Energy value of biogas	385 kWh/ ton of waste	840 kWh/ ton of waste
Generated electricity (30% efficiency)	116 kWh/ ton of waste	252 kWh/ ton of waste
Thermal energy (70% efficiency)	189 kWh/ ton of waste	412 kWh/ ton of waste
Thermal energy 80% of total obtained)	151 kWh/ ton of waste	329 kWh/ ton of waste

The production of energy from biogas is an energy-efficient process because the amounts of pollutants are very small, therefore they are not harmful to the environment. In addition to electricity and heat as the main products of biogas, another beneficial product obtained from anaerobic digestion should not be neglected, which is the digestate, which is rich in nitrogen and which in most cases can be used as fertilizer in agriculture.
Plants in the anaerobic digestion process do not have to be large-scale, which is why they are suitable for developing countries.

In this paper, while developing a model for utilizing the energy potential of municipal waste, an analysis of the sustainability of a biogas plant for the possible production of biogas in the Una-Sana Canton was performed, which would in further treatment be used for the production of electricity and heat energy using a possible cogeneration plant.

2.3. Analysis of a biogas plant for processing organic biodegradable waste

Based on data determined by research for the Una-Sana Canton area, Generated quantities of various types of municipal waste for treatment in the Una-Sana Canton area, it is necessary to calculate the daily quantity of organic waste delivered to the plant, with the indication that the plant operates 8,000 hours per year, as follows:

$$Md = \frac{13.306[t/year]}{8.000\left[\frac{h}{year}\right]} \cdot 24\ h = 39{,}9 \quad \left[\frac{t}{day}\right] \tag{1}$$

Based on the same and specific density of organic waste, it is necessary to calculate the volume of organic waste based on formula (2).

$$V = \frac{39{,}9\ \left[\frac{t}{day}\right]}{0{,}5\ \left[\frac{t}{m^3}\right]} = 79{,}8\ \left[\frac{m^3}{day}\right] \quad (2)$$

where is ite:

$\rho = 0{,}5\ \left[\frac{t}{m^3}\right]$ - specific density of organic waste (Rohlik, 2016)

To determine the radius of the digester, the height of the digester is taken arbitrarily, usually it is taken to be 4 m high, i.e. H=4 m, therefore when the volume is known, the diameter of the digester is calculated based on formula (3):

$$V = r^2 \cdot \pi \cdot H\ [m^3], \qquad r^2 = \frac{V}{\pi \cdot H} = \frac{79{,}8}{3{,}14 \cdot 4} = 6{,}35\ [m] \quad (3)$$

The diameter of the digester is 6,35 $[m]$.

The annual amount of biogas that can be produced in the plant is calculated using the formula (4)

$$Mbgod = 13.306\left[\frac{t}{year}\right] \cdot\ 150\ \ Qbyear = 1.995.900\left[\frac{m^3}{year}\right] \quad (4)$$

ρbs =150 m^3/t- specific amount of biogas [32]

To calculate the chemical energy contained in biogas, the calorific value of biogas is required. It can vary, and for the purposes of this calculation, 6.5 kWh/m3 is taken.
The chemical energy contained in biogas is calculated according to formula (5):

$$E = 1.995.900\ \left[\frac{m^3}{year}\right] \cdot 6{,}5\ \left[\frac{kWh}{m^3}\right] = 12.973.350\left[\frac{kWh}{year}\right] \quad (5)$$

The chemical energy contained in biogas on an annual basis amounts to $12.973.350\left[\frac{kWh}{year}\right]$.

When the chemical energy of biogas is known and the plant operates for 8,000 hours per year, the biogas power at the input to the cogeneration unit can be calculated using formula (6):

$$Pb = \frac{12.973.350\left[\frac{kWh}{year}\right]}{8.000[h/year]} = 1621{,}6\ [kW] \quad (6)$$

[32] *Rohlik, 2016 stranica 10-100*

In addition to biogas as a product obtained from a biogas plant, another product is compost, which is obtained based on the mass of biogas, which is the product of the specific density of biogas and the amount of biogas, as shown by formula (7):

$$mbgod\left[\frac{kg}{year}\right] = 0{,}717\ \left[\frac{kg}{m^3}\right] \cdot\ 1.995.900\left[\frac{m^3}{year}\right] = 1.431.060{,}3\left[\frac{kg}{year}\right] \quad (7)$$

ρ_b=0,717 $\left[\frac{kg}{m^3}\right]$ specific gravity of biogas [33]

When the mass of organic waste generated in the research area and the mass of biogas are known, the mass of digestate is the difference between these two masses, formula (8):

$$mD =\ 13.306\ \left[\frac{t}{year}\right] - 1431\ \left[\frac{t}{year}\right] = 11.875\ \left[\frac{t}{year}\right] \quad (8)$$

Analysis of the produced digestate through the literature concluded that it contains 40% water, which is removed, resulting in a dry digestate containing 50% fine compost that has its own value on the market, while the remaining 50% of the produced digestate is coarse compost that needs to be disposed of in a prescribed manner and will essentially represent a certain cost.

$$msd = 60\% \cdot 11.875\left[\frac{t}{year}\right] = 7.125\left[\frac{t}{year}\right]$$

Of this mass of dry digestate, 3562.5 [t/year] is fine compost intended for the market, while 3562.5[t/year] is coarse compost that will need to be disposed of in the prescribed manner and that is the cost.

2.4. Analysis of biogas cogeneration plant

When the basic elements of the analysis of a biogas plant and the products obtained from it are known, it is possible to perform an analysis of a cogeneration plant that will produce heat and electricity, assuming that the biogas engine has a 30% efficiency (Husika, 2016), and that the ratio of the thermal and electrical power of the biogas plant is $\frac{Pth}{Pe} = 1{,}7$ and that the annual number of working hours of the engine at full load is 8.000 h.
The electrical power of a biogas plant is calculated based on formula (9):

$$Pel = 1621{,}6 \cdot 0{,}3 = 486{,}5\ \ [kW] \approx 0{,}5[MW_{el}] \quad (9)$$

[33] *Nakomčić-Smaragdakis et al, 2013, stranica 101-106*

The annual electrical energy produced by a cogeneration plant is:

$$Eel = \ 8.000 \left[\frac{h}{god}\right] \cdot 0{,}5\ [MWel] = \ 4.000 \ \ \left[\frac{MWh}{year}\right] \quad (10)$$

Adopting the ratio of thermal and electrical power $\frac{Pth}{Pe} = 1{,}7$, the thermal power of the biogas plant can be calculated based on formula (11):

$$Pth = 1{,}7 \cdot 0{,}5 = 0{,}85\ [MW] \quad (11)$$

When the thermal power and the annual number of operating hours of the plant are known, it is possible to calculate the thermal energy produced in a biogas cogeneration plant on an annual basis using formula 1.12:

$$Qte = 8.000 \left[\frac{h}{year}\right] \cdot \ \ 0{,}85[MW] = 6.800 \ \ \left[\frac{MWh}{year}\right] \quad (12)$$

Considering that part of the heat (approximately 20%) is used to heat the digester, the amount of heat energy available for heating the buildings is 5.450 $\left[\frac{MWh}{year}\right]$, and the power available for heating buildings is ≈0.7 [MW].

Table 2. Products produced in a biogas cogeneration plant

Product	Annual production
Electric energy (MWh/year)	4.000
Heat (MWh/year)	6.800
Dry digestate (t/year)	7.125

The calculated heat, on average, is used to heat the digester, while the remaining heat power can be used to heat the surrounding residential units, so the heat used is calculated based on the available heat power (0.7 MW), the duration of the heating season in Bosnia and Herzegovina (180 days) and the load coefficient of the heat capacity of the plant available for heating in the territory of Bosnia and Herzegovina, which is 42%. (Husika, 2016.) Based on formula (13), the heat used for heating buildings is:

$$Qi = 0{,}7 \cdot 180 \cdot 24h \cdot 0{,}42 \approx 1270{,}1\ MWh \quad (13)$$

The amount of heat produced for use is 1270 MWh. If we know that the average consumption of final heat energy in households in Bosnia and Herzegovina is around 7900 kWh year[34], It can be concluded that 161 households can be supplied with heat from the biogas plant.

[34] *Agencija za statistiku BH, 2015*

2.5. Financial analysis of the viability of a biogas cogeneration plant

The financial analysis of a biogas cogeneration plant consists of calculating revenues from the sale of electricity, heat and fine compost, as well as calculating the costs of operating the plant, which consist of operating costs and costs of purchasing the plant (investment).
Based on the sales prices determined by the Energy Regulatory Commission of the Federation of Bosnia and Herzegovina - FERK, as well as the established incentive tariffs for electricity from biogas plants, it is possible to calculate the income from electricity, heat and fine compost. Since part of the electricity is needed for own consumption in biogas plants, this amount is reduced by 7.9%, and it amounts to 316 MWh on an annual basis, so that the part available for sale amounts to 3684 MWh, therefore the income from the sale of electricity is according to formula (14)

$$Pr_{el} = 3.684 \left[\frac{MWh}{year}\right] \cdot 278{,}9 \left[\frac{KM}{MWh}\right] = 1.027.467{,}6 \left[\frac{KM}{year}\right] \quad (14)$$

Revenue from the sale of thermal energy amounts to:

$$Pr_{th} = 1270{,}1 \left[\frac{MWh}{year}\right] \cdot 68 \left[\frac{KM}{MWh}\right] = 86.366{,}8 \left[\frac{KM}{year}\right] \quad (15)$$

Income from the sale of fine compost amounts to:

$$Pr_{k} = 3.562{,}5 \left[\frac{tona}{god}\right] \cdot 40 \left[\frac{KM}{tona}\right] = 142.500 \left[\frac{KM}{god}\right] \quad (16)$$

The cost of proper disposal of rough digestate amounts to:

$$T_{d} = 3.562{,}5 \left[\frac{t}{year}\right] \cdot 10 \left[\frac{KM}{t}\right] = 35.625 \left[\frac{KM}{year}\right] \quad (17)$$

Operating costs include annual labor costs, which are calculated based on the electrical power for the installed plant and amount to approximately 47.000 KM for this 500 kW plant, which was determined based on data that labor costs amount to 40.000 euros for an 830 kW plant, then annual plant maintenance costs amount to0,02 eura/kWh.[35] For the analyzed plant, the annual maintenance costs of the plant amount to 156.000 KM, because maintenance costs are calculated based on the product of the total energy contained in biogas, which for the analyzed plant amounts to 4.000.000 KWh/year and 0.02 euros/kWh.
Based on the above, it can be concluded that the operating costs (To) for the installed plant amount to 203.000 KM/year.

The net annual operating income of a biogas plant is calculated based on formula 1.14 and amounts to:

[35] *Kulić F., 2018*

$$NGP = 1.027.467{,}6 + 86.366{,}8 + 142.500 - 36.625 - 203.000 \quad (18)$$

$$NGP = 1.016.709{,}4 \ \left[\frac{KM}{year}\right]$$

In order to calculate the simple time period for the return on investment according to formula (19), it is necessary to calculate the investment cost, which, according to the available literature, for an installed plant with a capacity of 500 kWel is approximately 5.600 euros/kWel, which for the analyzed plant of 500 kWel is 5.460.000 KM. So the simple time period for the return on investment is:

$$JPP\ I = \frac{5.460.000\ [KM]}{1.016.709{,}4\ \left[\frac{KM}{year}\right]} = 5{,}37\ years)$$

The simple payback period is 5.37 years and as such represents an acceptable and sustainable project for investors, as it is considered that the payback period is attractive for investors up to 7 years.

3. Conclusion

In order to fulfill the national and strategic goals for waste management, and in order to achieve greater efficiency and sustainability of these projects, it is necessary to initially separate biodegradable waste from the rest of municipal waste, and based on the amount and composition of municipal waste in a certain area, along with determining its energy potential, it is also necessary to foresee the construction of a plant for the biological treatment of that waste. When dimensioning a facility for the biological treatment of separately collected biowaste in a certain area, as a basis for deciding on the investment of building the facility, it is necessary to collect the most accurate input data on the amount, composition and dynamics of waste generation in order to be able to choose the appropriate technology, that is, to choose the necessary optimal equipment.

In this paper, for the area of the Una-Sana Canton, where approximately 300.000 inhabitants live, based on the generated amount of biodegradable waste, an analysis of the sustainability of the operation of the biogas cogeneration plant was performed.

After sizing the biogas cogeneration plant, the results showed that by processing biodegradable waste in an amount of 79,8 m^3/day in the same can produce 4.000 MWh/year electricity, 6.800 MWh/year heat energy 7.125 tona/year of dry digestate.

The financial analysis showed that the sale of the mentioned products, and the included operating costs of the plant, can generate a net annual income in the amount of 1.016.709,4 KM.

Given that the cost of building this facility would cost 5.460.000 KM, the simple payback period of this investment was calculated in the amount of 5,37 years and as such is acceptable for investors.

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pH Values of Wide-Consumption Carbonated and Non-Carbonated Juices and Their Impact on Health Conditions

Sena Našić[1], Aida Šapčanin[2], Ekrem Pehlić[1], Azira Hrnjica[1], Lejla Hodžić[1] and Minela Ćejvan[1]

[1] Faculty of Health Studies, Bihać, Bosnia and Herzegovina
[2] Faculty of Pharmacy, Sarajevo, Bosnia and Herzegovina

E-mail: sena_nasic5@hotmail.com

Abstract. The pH value is a measure that determines the acidity or alkalinity of a liquid on a scale from 0 to 14. Carbonated beverages, due to the presence of carbon dioxide and additional acids, typically have a low pH, making them acidic. This characteristic affects not only their taste but also their impact on health. Carbonated drinks are acidic due to the carbonic acid formed through carbonation and additives such as phosphoric or citric acid. Their pH usually ranges between 2.5 and 4.0, making them significantly acidic. Despite their popularity, moderate consumption is essential to prevent long-term health issues. Awareness of the composition and the effects of pH values on health can help consumers make informed decisions regarding the consumption of these beverages. The consumption of drinks with low pH values can cause significant problems in the human digestive system. In individuals with gastroesophageal reflux disease (GERD), acidic beverages can trigger symptoms such as heartburn and discomfort. Carbonated drinks have properties that can worsen GERD due to their high acidity and carbonation. They also negatively impact dental health by promoting enamel erosion and increasing the risk of cavities, particularly with frequent consumption. The objective of this study was to analyze the pH values of various commercially available carbonated and non-carbonated juices and assess their potential impact on human health. Measurements were conducted using a digital pH meter, model WA-2017SD, calibrated with standard solutions. The measured pH values of the analyzed samples ranged from 2.89 to 3.71. The lowest pH was recorded in Sinalco Cola, while the highest was in Orangina. The pH values of non-carbonated juices were higher, ranging from 3.03 to 4.26. The lowest was in Fructal Double C, while the highest was in Frovita. The analyzed samples of non-carbonated juices exhibited higher pH values compared to carbonated juices, indicating that carbonated juices may pose a greater health risk. In conclusion, moderate consumption of both carbonated and non-carbonated juices, along with monitoring their composition, is essential for reducing health risks. Consumer education on potential harmful effects and the promotion of alternatives with higher pH values, such as water or natural juices without added CO_2, is recommended.

Keywords: pH value, carbonated juices, non-carbonated juices, acidity, health effects

1. Introduction

In modern lifestyles, the consumption of carbonated and non-carbonated soft drinks has become an almost daily habit for a large number of people, especially among the younger population. The availability and popularity of these mass-consumed beverages have significantly increased, yet their chemical composition and potential impact on health are often overlooked [1]. One of the key factors that can affect the human body is the pH value of these drinks, which determines their acidity or alkalinity. Acidic liquids, particularly those with low pH values, can have a negative effect on tooth enamel, the mucous membrane of the digestive system, and may potentially contribute to the development of various health problems [2]. The consumption of drinks with low pH values can have adverse effects on health, particularly on the digestive system and tooth enamel [3]. In individuals with gastroesophageal reflux disease (GERD), acidic beverages can worsen symptoms such as heartburn and discomfort [4]. Furthermore, frequent exposure to acidic drinks can lead to dental erosion, or the gradual wearing down of tooth enamel, which increases the risk of cavities and tooth sensitivity [5]. In light of this, it is important to investigate the actual pH values of popular commercial beverages and to inform the public about their potential health impacts. The aim of this paper is to analyze the pH values of selected carbonated and non-carbonated soft drinks available on the market, and to consider the possible health consequences of their consumption, with an emphasis on preventing negative effects and promoting healthier choices among consumers.

2. Methods

For the purposes of this research, the pH values of selected carbonated and non-carbonated soft drinks commercially available on the market were measured. The samples were randomly selected with the aim of covering a variety of brands and types of beverages in order to obtain a representative overview of the acidity of mass-consumed drinks. The pH measurements were conducted using a WA-2017SD digital pH meter, known for its high precision and ease of use in laboratory settings [6].

All samples were brought to room temperature (approximately 25 °C) prior to measurement, and each sample was tested in triplicate to minimize potential errors and increase data reliability. The results were analyzed and compared between carbonated and non-carbonated drinks, with particular emphasis placed on the differences in pH values and the potential health risks that may arise from their regular consumption.

Table 1. Overview of carbonated juices

Name of the juice	pH	temperature
Pepsi	2,98	25℃
Sinalco cola	2.89	25℃

Cocta	3.13	25°C
Sky cola	2,91	25°C
Cola	2,94	25°C
Schweppes	3,12	25°C
Fanta	3,25	25°C
Orangina	3,71	25°C
Sanpellegrino Natural	3,58	25°C
Sinalco fanta	3,00	25°C

Figure 1. Overview of carbonated juices used in the study.

Table 2. Overview of non-carbonated juices

Name of the juice	pH	temperature
Fructal Double C	2,98	25°C
Rauch	2.89	25°C
Fruvita	3.13	25°C

Juicy	2,91	25°C
Fructal Apple	2,94	25°C
Juicy Apple	3,12	25°C
Rauch Apple	3,25	25°C
Fruvita Apple	3,71	25°C
Vitaminka Orange	3,58	25°C
Vitaminka Apple	3,00	25°C

Figure 2. Overview of non-carbonated juices used in the study.

3. The Impact of carbonated drink consumption on human health

Carbonated soft drinks, especially those sweetened with sugar, are associated with a range of adverse effects on human health [7]. Their regular consumption may contribute to the development of various health issues, including obesity, type 2 diabetes, cardiovascular diseases, dental erosion, and decreased bone density. The consumption of sugar-sweetened carbonated beverages significantly increases calorie intake, which can lead to weight gain and obesity [8]. Additionally, these drinks often replace more nutrient-rich options such as milk, thereby reducing the intake of

essential nutrients. Regular consumption of sweetened carbonated beverages has been linked to an increased risk of cardiovascular diseases. A meta-analysis of seven prospective cohort studies showed that a higher intake of these drinks may increase the risk of stroke and myocardial infarction [9,2]. High consumption of carbonated beverages can also negatively affect bone health [10]. A study conducted in China found that individuals who consume carbonated drinks daily have a significantly higher risk of bone fractures compared to those who do not consume them [2]. The acidity of carbonated beverages can also cause erosion of tooth enamel [5,11]. This erosion increases the risk of cavities and tooth sensitivity. A review of the literature suggests that the consumption of these drinks may significantly contribute to dental problems, particularly among children and adolescents.

4. Results

A total of 10 samples of carbonated and 10 samples of non-carbonated commercially available soft drinks were analyzed in this study to determine their pH values and to compare the potential health impact of their acidity. All samples were brought to room temperature (25 °C) prior to testing, and measurements were conducted in triplicate using a digital pH meter (WA-2017SD).

The pH values of the carbonated drinks ranged from 2.89 to 3.71. The lowest pH value was recorded in the Sinalco Cola sample (pH 2.89), while Orangina had the highest (pH 3.71). Most carbonated soft drinks exhibited high acidity, with pH values below 3.2, classifying them as highly acidic beverages. This acidity is primarily attributed to the presence of carbonic acid, along with added phosphoric and citric acids, which are commonly used to enhance flavor and preserve the product. Such pH values are particularly concerning from a dental health perspective, as prolonged and frequent consumption may lead to erosion of tooth enamel and can also aggravate symptoms of gastroesophageal reflux disease (GERD). The pH values of non-carbonated drinks showed a wider range and were, on average, higher than those of carbonated drinks, indicating lower acidity. The values ranged from 3.03 (Fructal Dvojni C) to 4.26 (Fruvita).

Although non-carbonated juices contain natural acids such as malic and citric acid, they generally lack carbon dioxide and phosphoric acid, contributing to their lower acidity. While their pH values are more favorable compared to carbonated beverages, some samples, such as Fructal Dvojni C (pH 3.03), are still acidic enough to potentially harm tooth enamel if consumed frequently and without rinsing the mouth with water afterward. Based on the results, it can be concluded that carbonated soft drinks are significantly more acidic and therefore potentially more harmful to health, especially when consumed frequently and in large quantities. Moderate consumption and the selection of drinks with higher pH values are recommended as part of healthy dietary habits.

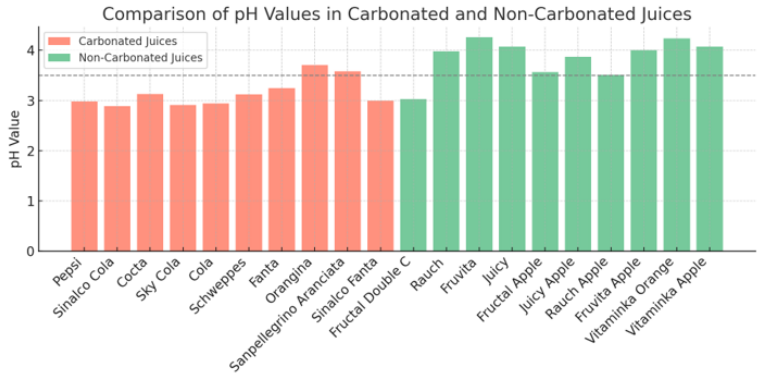

Figure 3. Comparison of pH Values in Carbonated and Non-Carbonated Juices.

5. Conclusion

The research on the pH values of commercially available carbonated and non-carbonated soft drinks confirmed that carbonated beverages have significantly lower pH values, making them more acidic and potentially more harmful to human health. The lowest measured pH values among carbonated drinks were below 3.0, while non-carbonated drinks had slightly higher values, although some samples still showed notable acidity. Low pH levels in beverages are associated with an increased risk of dental erosion, worsening of gastroesophageal reflux disease (GERD), reduced bone density, and a higher risk of metabolic disorders such as obesity and diabetes. Given that most of the analyzed carbonated drinks had pH values within a range that contributes to enamel damage and digestive system irritation, limited consumption of these beverages is recommended. It is important to highlight the need for consumer education regarding the harmful effects of acidic beverages and to encourage the selection of healthier alternatives such as water, natural juices without added sugar, and drinks free of carbon dioxide. Making informed dietary choices is essential for maintaining both oral and general health.In conclusion, the results of this study emphasize the need for greater caution in the consumption of both carbonated and non-carbonated soft drinks and underline the importance of informing consumers about their composition and potential health consequences.

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Concentration of heavy metals in human hair samples of different age groups

Aida Džaferović [1], Ekrem Pehlić[2], Kemal Salkić[3], Azira Hrnjica[2], Sena Našić[2] and Lejla Hodžić[2]

[1] Biotechnical faculty, Bosna i Hercegovina, Bihać
[2] Faculty of Health Studies, Bosna i Hercegovina, Bihać
[3]Agricultural Institute, Bosna i Hercegovina, Bihać

E-mail: pehlic_ekrem@yahoo.com

Abstract: Heavy metals pose a potential risk to human health due to their toxicity and ability to accumulate in the body. Hair is increasingly used as a biomarker for assessing long-term exposure to these elements, as it allows for the detection of metals introduced through food, water, and air. Human hair is composed of protein fibers primarily made of α-keratin. Keratin consists of numerous sulfhydryl groups, to which metals have a high affinity, making them easily incorporated into the hair structure. Metals also have the ability to bind to the hydrophobic regions of melanin polymers. Therefore, human hair serves as an excellent medium for monitoring heavy metals in the human body. The aim of this study was to determine how different parameters, such as age, gender, and smoking habits, influence the presence of heavy metals (Cr, Cd, Pb, Fe, and Co) in human hair. The analysis of samples was performed using atomic absorption spectrophotometry (AAS) with a "Perkin Elmer" AAnalyst-800 atomic absorption spectrophotometer, equipped with Zeeman correction (flame technique). This method enables precise quantification of trace elements. Analysis of ten human hair samples revealed that lead concentrations ranged from 0.040 to 0.047 mg/kg, while cadmium concentrations varied between 0.022 and 0.270 mg/kg, with some samples showing significantly higher values. Cobalt was present in concentrations of 0.011–0.012 mg/kg, whereas iron concentrations were extremely low, ranging from 0.001 to 0.004 mg/kg. Chromium concentrations showed a slight increase in some samples, ranging from 0.002 to 0.015 mg/kg. The results indicate variability in heavy metal concentrations among participants, with cadmium levels in some samples showing significant deviations. This difference may be attributed to varying exposure to environmental pollutants. The study confirmed that age, gender, and lifestyle habits influence the presence of heavy metals in hair. As a medium for monitoring heavy metal concentrations, human hair proves to be a valuable analytical tool due to its simplicity, availability, and non-invasive sampling process. The obtained results highlight the importance of continuous monitoring of heavy metal exposure, as well as the need to raise awareness of their health effects and possible preventive measures.

Keywords: heavy metals, human hair, environment

1. Introduction

Heavy metals are ubiquitous in the environment and represent a serious public health concern due to their ability to bioaccumulate and exert toxic effects on the human body. Although some of them are essential in trace amounts for normal physiological function, others—such as lead (Pb) and cadmium (Cd)—have no known physiological role and are highly toxic even at low concentrations [1,2]. These metals enter the human body through contaminated food, water, air, and consumer products, including cosmetics. Prolonged exposure can result in numerous health problems, including damage to the liver, kidneys, nervous system, and various forms of cancer [3,4]. Monitoring exposure to heavy metals can be conducted through various biological samples—blood, urine, nails, and hair. In recent decades, hair has increasingly been used as a biomarker due to its ability to reflect chronic exposure and accumulate metals over time [5,6]. Unlike blood and urine, which provide insight into acute or current exposure, hair enables analysis over a longer period due to its continuous growth structure and stable binding of metals to keratin and melanin structures [7].

The structure of hair, rich in α-keratin and cysteine, contains sulfhydryl (-SH) groups that have an affinity for metals and enable their stable incorporation. Additionally, melanin in hair can bind metal ions through its hydrophobic components [8]. The most commonly analyzed metals in hair include: lead (Pb), cadmium (Cd), cobalt (Co), iron (Fe), chromium (Cr), nickel (Ni), zinc (Zn), copper (Cu), arsenic (As), mercury (Hg), and manganese (Mn) [9,10]. The concentrations of these metals can vary significantly depending on geographic and environmental factors, age, sex, smoking habits, diet, and exposure to industrial sources [11]. A study conducted in Iran found that concentrations of heavy metals in the hair of urban residents were significantly higher compared to other global studies, with dominant presence of Pb, Cd, Fe, and Zn, which is linked to urban traffic, industrial emissions, and dietary quality [12]. Similarly, a study conducted in Bosnia and Herzegovina revealed significantly higher concentrations of lead, cadmium, and cobalt in children with autism spectrum disorders, confirming the potential impact of these elements on neurological development [13]. In the context of environmental exposure, hair analysis can help identify sources of contamination. For example, smoking has been recognized as a significant factor contributing to increased levels of Cd, Pb, and As in the hair of subjects [14], while older individuals show higher levels of accumulated metals due to their bioaccumulative nature [15]. Another additional source of contamination with heavy metals is cosmetic products, including hair dyes. Studies have shown that many commercial dyes, particularly darker shades, contain traces of lead, cadmium, and cobalt—even though some of them are banned in the EU under Regulation 1223/2009 [16]. Analyses of samples available on the market in Bosnia and Herzegovina confirmed the presence of these metals in almost all tested products, indicating insufficient regulation and control [17]. Despite the advantages of the method, hair analysis also has its limitations. Cosmetic treatments such as dyeing, bleaching, and exposure to UV

radiation can alter the metal content in the outer layers of hair. Therefore, proper washing and sample preparation are necessary before analysis to remove external contaminants and ensure the reliability of results [18]. Methods for heavy metal analysis include sophisticated techniques such as atomic absorption spectrometry (AAS), inductively coupled plasma mass spectrometry (ICP-MS), and laser ablation. The choice of method depends on the research goals, available equipment, and the number of elements to be analyzed simultaneously [19]. Given the ubiquity of heavy metals and their potentially harmful effects, hair analysis represents a valuable non-invasive method for biomonitoring populations, especially in areas with pronounced industrial and urban activity. The aim of this research was to determine the presence and concentrations of lead, cadmium, cobalt, iron, and chromium in human hair samples of individuals of different ages using the atomic absorption spectrometry (AAS) method, and to analyze possible differences in concentrations in relation to age and other relevant factor.

2. Materials and methods

In this study, ten human hair samples collected from individuals of different age groups were analyzed to determine the concentrations of heavy metals: lead (Pb), cadmium (Cd), cobalt (Co), iron (Fe), and chromium (Cr). Hair samples were taken from the occipital region of the scalp, with a length of approximately 3–5 cm, covering a hair growth period of about three months. After collection, the samples were stored in sterile plastic containers, labeled with identification codes, and kept at room temperature until the time of analysis.

Prior to chemical analysis, the hair was subjected to ashing and digestion preparation processes, in accordance with laboratory standards for the preparation of biological material for metal analysis. This ensured homogenization of the sample and the release of metals from the keratin matrix.

Table 1. Recommended operating conditions for the detection of analyzed metals

Element	Pb	Cd	Co	Fe	Cr
Flame	Air–acetylene	Air–acetylene	Air–acetylene	Air–acetylene	Air–acetylene
Wavelength (nm)	283.3 nm	228.8 nm	240.7 nm	243.3 nm	357.9 nm
Slit width (nm)	0.7	0.7	0.7	0.7	0.7

Mode	AA-BG	AA-BG	AA-BG	AA-BG	AA-BG
Burner height	10 cm	10 cm	10 cm	10 cm	10 cm
Nebulizer	High sensitivity	High sensitivity	High sensitivity	High sensitivity	High sensitivity
Signal measurement	Peak area	Peak area	Peak area	Peak area	Peak area
Calibration method	Linear / zero	Linear / zero	Linear / zero	Linear / zero	Linear / zero

Source: [20]

The analysis was performed using the atomic absorption spectrometry (AAS) method, with a Perkin Elmer Analyst – 800 instrument equipped with Zeeman effect modulation. Detection was carried out using an air–acetylene flame, with individually adjusted conditions for each analyzed metal, including appropriate wavelengths, nebulizer types, and calibration methods.

Measurements were performed using the peak area analysis mode, applying a linear calibration model with a zero intercept. Certified standard solutions were used, prepared according to the manufacturer's recommendations (Perkin Elmer Instruments). The analytical results were expressed in milligrams per kilogram (mg/kg) of hair sample.

3. Results

In this study, the determination of heavy metal concentrations in human hair samples was carried out using atomic absorption spectrometry (AAS) with the Perkin Elmer Analyst – 800 instrument. Prior to the analysis, optimal technical conditions for the detection of each analyzed metal were established. The recommended operating conditions are presented in Table 1, which includes the specific wavelengths (nm), flame type, slit width, measurement mode (AA-BG), nebulizer type, calibration models, and the certified standard solutions used for each metal. These parameters ensured maximum sensitivity and accuracy in the measurement of metals such as lead (Pb), cadmium (Cd), cobalt (Co), iron (Fe), and chromium (Cr).

After the optimization of conditions, the analysis of ten human hair samples from individuals of varying ages was conducted. The obtained results are presented in the table.

Table 2. Results of Heavy Metal Analysis

Sample	Pb (mg/kg)	Cd (mg/kg)	Co (mg/kg)	Fe (mg/kg)	Cr (mg/kg)
1.	0,040	0,244	0,011	0,002	0,002
2.	0,044	0,086	0,011	0,001	0,003
3.	0,045	0,122	0,011	0,001	0,004
4.	0,046	0,139	0,011	0,002	0,008
5.	0,047	0,270	0,012	0,003	0,010
6.	0,045	0,022	0,012	0,002	0,012
7.	0,042	0,267	0,012	0,003	0,013
8.	0,041	0,028	0,012	0,003	0,013
9.	0,045	0,051	0,012	0,003	0,013
10.	0,045	0,057	0,012	0,004	0.015

The concentrations of lead in the analyzed hair samples ranged from 0.040 to 0.047 mg/kg. The lowest measured value (0.040 mg/kg) was recorded in Sample 1, while the highest (0.047 mg/kg) was found in Sample 5. Most samples showed similar values (between 0.041 and 0.046 mg/kg), indicating a relatively stable and uniform level of lead exposure among the majority of the analyzed individuals. The Pb concentrations in all samples were within a very narrow range, without any significant deviations or extreme values. (Figure 1.)

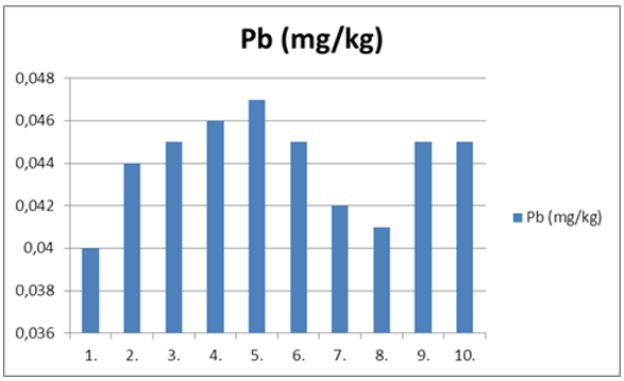

Figure 1. Lead (Pb) Concentration

Cadmium showed significantly greater fluctuations in concentrations compared to the other metals. Cd values ranged from 0.022 mg/kg (Sample 6) to as high as 0.270 mg/kg (Sample 5). Elevated concentrations were observed in Sample 5 (0.270 mg/kg), Sample 7 (0.267 mg/kg), Sample 1 (0.244 mg/kg), and Sample 4 (0.139 mg/kg), while Samples 6, 8, and 9 had notably lower levels (below 0.060 mg/kg). These elevated cadmium concentrations in certain samples may indicate higher exposure of the participants to external factors such as environmental pollution, dietary habits, and smoking. (Figure 2.)

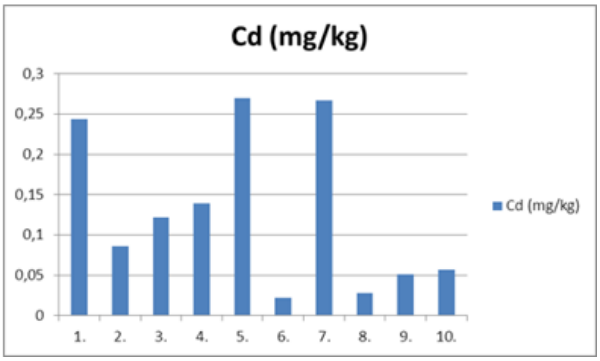

Figure 2. Cadmium (Cd) Concentration

In all analyzed samples, cobalt concentrations were within a very narrow range of 0.011 to 0.012 mg/kg. A value of 0.011 mg/kg was recorded in Samples 1 through 5, while a concentration of 0.012 mg/kg was measured in Samples 6 through 10. These cobalt concentrations suggest that all individuals had relatively uniform exposure. Cobalt was the only analyzed metal that did not show significant deviations from the standard concentration value. (Figure 3.)

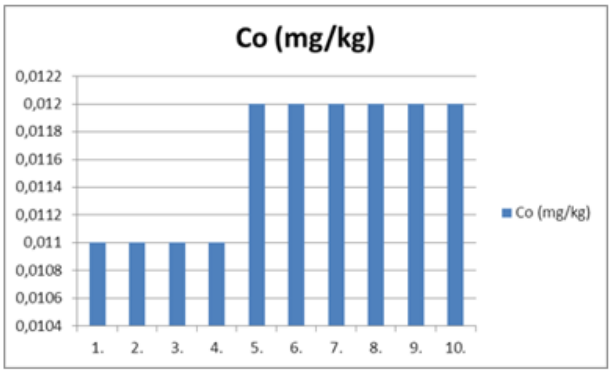

Figure 3. Cobalt (Co) Concentration

Iron concentrations in the hair samples ranged from 0.001 to 0.004 mg/kg. The lowest value (0.001 mg/kg) was recorded in Samples 2 and 3, while the highest (0.004 mg/kg) was measured in Sample 10. A slight increase in iron concentrations (0.002–0.004

mg/kg) was observed in Samples 6 to 10, whereas values in Samples 1 to 5 were lower and more stable. As an essential element, iron is present in small amounts, and the variations in results may be related to individual metabolic or dietary factors. (Figure 4.)

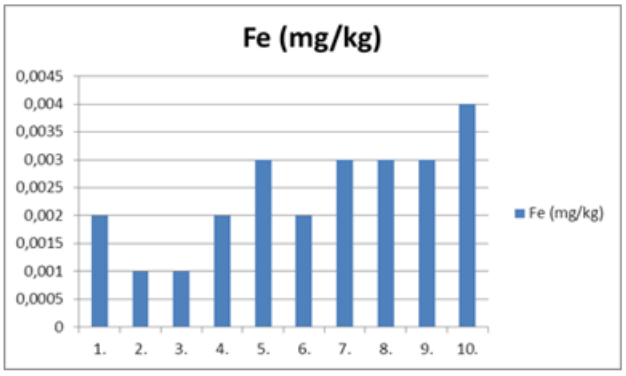

Figure 4. Iron (Fe) Concentration

Total chromium concentrations in the hair samples ranged from 0.002 to 0.015 mg/kg. The lowest values (0.002 mg/kg) were measured in Samples 1 and 2, while the highest concentration (0.015 mg/kg) was recorded in Sample 10. Samples 3 to 5 showed a gradual increase (0.004–0.010 mg/kg), and from Sample 6 onwards, total chromium concentrations exhibited a slight but consistent rise. Overall, an increase in Cr concentrations was observed in samples with higher sequence numbers, which may suggest a possible association with age, habits, or other lifestyle factors. (Figure 5.)

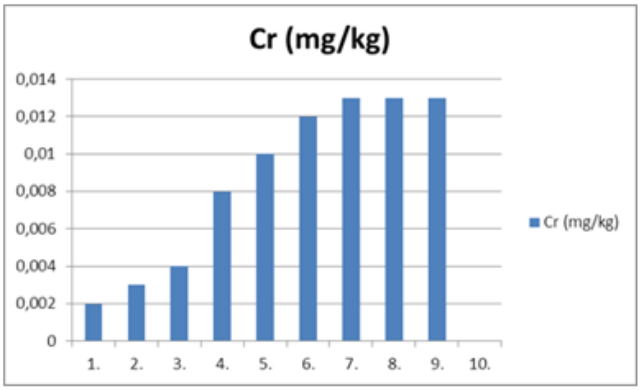

Figure 5. Chromium (Cr) Concentration

4. Discussion

The results of the study showed that all tested metals (Pb, Cd, Co, Fe, and Cr) were present in all human hair samples. The greatest variation was observed in cadmium concentrations, ranging from 0.022 to 0.270 mg/kg. This difference can be explained by

individual variations in lifestyle, diet, exposure to tobacco smoke, and residence in industrial areas, which aligns with findings from previous studies [6,8,12]. Lead concentrations were relatively uniform (0.040–0.047 mg/kg), confirming the ubiquitous presence of this metal in the environment. Although the measured values were low, continuous exposure to lead, especially in combination with other metals, may pose a health risk due to its ability to accumulate in tissues, particularly in bones and the central nervous system [2,9]. Stable cobalt concentrations (0.011–0.012 mg/kg) indicate that this element was present within reference limits, as expected, since Co is an essential micronutrient required for vitamin B12 synthesis [4].

However, chronically elevated amounts may have harmful effects, as demonstrated in industrially exposed populations [13]. Regarding iron and chromium, a slight increase in concentrations was noted in older participants, consistent with previous studies indicating that these metals can accumulate in the body over time [15,16]. Due to the limited number of samples in this study, no statistically significant correlations can be confirmed; however, a potential trend of increasing values with age is observed. These results are supported by the study of Pehlić et al. (2019), which showed that cosmetic products available on the domestic market contain significant amounts of Pb, Cd, Co, and Fe. Using the same analytical method—atomic absorption spectrometry—lead and cadmium concentrations exceeding recommended values were detected [17]. These findings further emphasize the need for continuous monitoring and stricter regulation of heavy metal presence in everyday products.

5. Conclusion

The obtained results of the study confirm the presence of heavy metals (Pb, Cd, Co, Fe, and Cr) in all analyzed human hair samples from individuals of different ages. The analysis indicated certain variations in metal concentrations among the subjects, with the greatest differences observed for cadmium, while cobalt concentrations were exceptionally stable and uniform.

A notable increase in Cd concentrations was observed in some samples, indicating potential elevated exposure to this toxic metal, likely influenced by factors such as smoking, contaminated diet, or environmental pollution. Given the high toxicity and cumulative nature of Cd and Pb, their presence even at very low concentrations demands attention and further monitoring. The values of iron and chromium suggest a possible age-related effect, with a slight increase in older subjects, confirming metal accumulation with advancing age.

Human hair once again proved to be a very effective biological indicator for assessing exposure to heavy metals, primarily due to its capacity for long-term metal retention, ease of collection, and non-invasiveness.

It is important to emphasize that the sample size in this study was limited (n = 10), which represents a methodological limitation. A larger sample size was not feasible due to restricted technical and financial resources. Therefore, although the results provide

valuable insight, they should be interpreted with caution and not generalized to the broader population.

It is recommended that future studies include a larger number of samples, as well as additional demographic and other parameters (gender, occupation, habits, diet), along with correlations with biochemical markers from blood and urine for a more comprehensive understanding of systemic exposure levels.

In conclusion, continuous monitoring of heavy metal presence in everyday products and the environment is essential, alongside raising public awareness about the risks of chronic exposure to these elements, especially in vulnerable populations. Preventive measures, education, and stricter regulation of cosmetic and food products remain key tools in reducing the dangers of toxic metals in modern society.

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The Influence of Agroecological Factors on the Yield of Selected Maize (Zea mays L.) Hybrids in Bosnia and Herzegovina

Sarajlija Adel, Dizdarić Tanja, Emir Mujić, Toromanović Merima and Mirsad Ičanović

Biotehnički fakultet Univerzitet u Bihaću

E-mail: adel_sara@hotmail.com

Abstract. The aim of this study was to determine the impact of agroecological conditions in different growing areas on the grain yield of four maize hybrids (O 3397 FAO 380, OS Semper FAO 490, OS Singular FAO 640, and OS Rudolfov 60 FAO 650). A field trial was established at four locations across Bosnia and Herzegovina, where the hybrids were grown under standardized agronomic conditions. At the end of the growing season, grain yield was measured and adjusted to a standard moisture content of 14%. The obtained data were analyzed in the context of agroecological factors specific to each location. The results of this study may contribute to a more efficient selection of maize hybrids based on regional agroecological characteristics, thereby optimizing maize production in Bosnia and Herzegovina.

1. Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops worldwide and forms the basis of the food system in many countries. Its significance lies in its diverse applications—in human nutrition, animal feed, and industrial processing [10]. As a highly adaptable crop, maize is grown in a variety of agroecological zones; however, it remains particularly sensitive to climatic factors during key growth and developmental stages [7].In recent decades, climate change—particularly the rise in average temperatures, altered precipitation patterns, and increased frequency of extreme weather events—has increasingly affected both the stability and magnitude of maize yields. It is estimated that a temperature increase of just 1 °C could reduce maize yields in tropical and subtropical regions by up to 10% [14]. These changes have direct implications for food security, especially in regions where maize serves as a dietary staple.

In this context, the importance of applying the principle of a Sound Scientific Basis is increasing. This principle emphasizes systematic data collection, comprehensive understanding of local agro-climatic conditions, and crop yield modeling in relation to projected climate change scenarios. Key adaptation strategies include the selection of climate-resilient crop varieties, optimization of sowing dates, and more efficient management of water and nutrient resources [13].

Objective of the Experiment

The objective of the experiment is to determine the influence of various factors (e.g., maize hybrids and agroecological conditions of the location, with an emphasis on the amount of precipitation) on maize yield, using the split-plot design as the experimental methodology.

2. Materials and Methods

2.1. Location of the Experiment and Metodhs

The aim of the study was to examine the impact of agroecological conditions on three maize hybrid varieties: OS 3397, OS Semper, and OS Rudolfov 60. The trials were established using a split-plot design with four replications across six different locations in Bosnia and Herzegovina: Velika Kladuša, Brčko, Kalesija, Gradiška, Srbac, and Kozarska Dubica. Standard agronomic practices and conventional farming principles were applied, adapted to the conditions of dryland farming, which have traditionally been used for maize cultivation in this region [5].

The split-plot method is an experimental design used in studies where factors have different levels of application or when it is inefficient or impractical to apply all treatments uniformly to entire experimental units. In this study, the main treatment was the maize hybrid, while the subplot treatment was the growing location.

This design allows for more efficient control of variability within the experiment, especially when factors differ in nature or scale, and enables more precise examination of interaction effects between factors. The split-plot method is commonly applied in agricultural research where it is logistically demanding or uneconomical to apply treatments over large areas, as is the case with different growing locations or genotypes [8];[15]. Maize yield was measured after harvest from individual plots and expressed in kilograms per hectare (kg/ha). Measurements were taken on fully matured grain.

Due to the influence of grain moisture content on the weight of the yield, all yields were standardized to a moisture content of 14% [2].

Data were analyzed using analysis of variance (ANOVA) adapted for the split-plot design to evaluate the effects of main plots, subplots, and their interaction, with the significance level set at $p < 0.05$ [6].

3. Results and Discussion

The evaluation of maize hybrid yield under different agronomic conditions is essential for selecting high-performing genotypes that can enhance food security and optimize resource use efficiency [6].

The results of this study indicate that the hybrid factor has a statistically significant effect on maize yield, whereas location did not show a significant difference under the specific experimental conditions. These findings are consistent with numerous previous studies highlighting the critical role of hybrid genetic potential in determining yield performance.

Table 1. The influence of Maize Hybrid and Location on Grain Yield (t/ha)

Source of variation	SS (Sum of Squares)	df (Degrees of Freedom)	MS (Mean Square)	F	p-same
Hybrid	6.84	2	3.42	8.55	0.00905
Location	2.35	2	1.18	2.95	0.8388
Error	1.60	4	0.40		
Sum	10.79	8			

The hybrid factor has a statistically significant effect on yield ($p < 0.05$). The location factor does not have a statistically significant effect ($p > 0.05$).

For example, [9] reported that certain hybrids demonstrated significant adaptability and yield stability, regardless of variations in agroecological conditions. Similarly, [16] stated that genotype (hybrid) contributed more to overall yield variability than location, which further supports our findings. Analysis of variance (ANOVA) revealed significant effects of genotype (G), environment (E), and their interaction (G×E) on maize yield ($p < 0.01$). Our findings align with previous studies emphasizing the dominant role of G×E interactions in yield variability. For instance, [1] reported that the environment accounted for 25.1% of the total variation, genotype for 35.2%, and G×E interaction for 21.2%. Similarly, [19] observed that G×E interactions explained 80.36% of the variation, with genotype and environment contributing 12.79% and 6.85%, respectively. These results underscore the importance of considering both genetic and environmental factors in maize breeding programs.

Conversely, in the study by [4], location had a significant effect on yield, particularly in cases where moisture availability and soil types differed substantially. The discrepancy between their results and ours may be attributed to the more homogeneous nature of our experimental sites—all three locations were within the same agro-climatic zone, with similar soil characteristics and rainfall patterns during the growing season. For example, the hybrid 'SMH_1706' exhibited consistent performance across all test locations, demonstrating its adaptability to varying environmental conditions. This finding is consistent with studies by [3] who reported that certain maize hybrids displayed significant adaptability and yield stability across diverse agro-ecological zones. Similarly, [1] highlighted the utility of AMMI and GGE biplot analyses in identifying stable genotypes in multi-environment trials.

Additionally, possible differences in management practices (e.g., agronomy, irrigation, fertilization) between locations may not have been pronounced enough to result in significant yield variations. In this context, the importance of location as a factor could be more evident in broader geographic settings with stronger environmental contrasts, as shown in the work of [12], where location had a strong effect on yield across distinctly different climatic regions.

Table 2. The climatic factors of the most important parameters in the studied areas, source: Federal Hydrometeorological Institute

Location	Avg. Temp. (°C)	Max Temp. (°C)	Min Temp. (°C)	Precipitation (mm)	Rainy Days	Humidity (%)
Gradiška	23.1	30.0	16.0	79.9	9	68
Srbac	23.0	36.0	13.0	88.0	9	64
V.Kladuša	28.6	36.0	14.0	91.0	13	72
K.Dubica	28.7	33.0	17.0	77.0	7	61
Brčko	30.9	39	19	76.0	6	61

Our findings confirm that the genetic potential of the hybrid is a key factor for achieving high yields, while the effect of location may vary depending on specific conditions and should be carefully considered in crop planning. Our study was conducted in homogeneous agro-climatic conditions; however, micro-environmental variations within the experimental sites may have influenced yield outcomes. [18] noted that differences in precipitation, particularly between June and July, can significantly affect maize yield. These findings suggest that even within the same agro-climatic zone, subtle environmental differences can impact hybrid performance, emphasizing the need for comprehensive environmental assessments in breeding programs.

4. Conclusion

This study confirms that the genotype of maize hybrids significantly influences grain yield, while the effect of location was not statistically significant under the specific experimental conditions. These findings suggest that the genetic potential of hybrids plays a more critical role than local agroecological variability within similar climatic zones**.** The application of a split-plot design proved effective in evaluating the interactions between hybrids and growing locations, allowing for precise interpretation of the factors affecting yield. Additionally, standardizing grain yield to 14% moisture content ensured accurate and comparable results across treatments. These results underscore the importance of selecting high-yielding and adaptable maize hybrids as a key strategy for optimizing production and enhancing food security, especially in regions with relatively uniform agroclimatic conditions. However, in areas with greater environmental heterogeneity, location-specific factors may become more prominent and should be carefully integrated into crop management decisions. Recommendations' for Maize Cultivation in Bosnia and Herzegovina:

- Select High-Yielding and Adaptable Hybrids: Choose hybrids that have demonstrated consistent performance across various environments to ensure stable yields.
- Implement Precision Agriculture Practices: Utilize technologies that allow for precise monitoring and management of growing conditions to optimize production and reduce the impact of environmental variability.

- Educate Farmers on Best Practices: Provide training and information on optimal maize cultivation techniques, including appropriate hybrid selection, planting schedules, and crop management practices.

In conclusion, our findings affirm that the genetic potential of maize hybrids is a critical determinant of yield performance. However, the influence of genotype-by-environment interactions should not be underestimated. Therefore, comprehensive evaluation of hybrids across multiple environments is essential for identifying genotypes with both high yield potential and stability, thereby contributing to enhanced food security and resource use efficiency in maize production.

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CBAM Reporting for steel and aluminium products

Vera Tarlać

Agency "TQ Net Consulting", Trg zlatnih ljiljana 29, 71000 Sarajevo

E-mail: office@tqnet-consulting.com

Abstract. This paper presents the key elements of reporting according to the CBAM regulation of the European Union for steel and aluminum products.
The Carbon Border Adjustment Mechanism (CBAM) is a European Union regulatory framework aimed at reducing carbon dioxide emissions for certain products, including steel and aluminum. The goal of CBAM is to ensure a level playing field between producers within the EU, who are already subject to stricter climate regulations, and producers from third countries.
Key elements of CBAM reporting are:
• Product coverage – CBAM applies to the import of steel, aluminum and other products with a high carbon footprint.
• Obligations of importers - EU importers must report quarterly on CO2 emissions related to products and pay the appropriate fee.
• Calculation of emissions – The calculation of emissions includes direct and indirect emissions associated with products delivered to the EU.
• Transition phase – transitional period in which only reporting is mandatory, the period from which CBAM certificate collection will begin.
• Impact on the economy – CBAM can have a significant financial and operational impact on companies exporting to the EU, requiring strategic adjustment.
CBAM reporting is a key part of the EU's strategy to achieve climate neutrality and reduce global emissions. Companies in the steel and aluminum sector need to develop adequate monitoring and reporting systems in order to meet regulatory requirements and remain competitive on the EU market.

1. Introduction

The topic of climate change is one of the most important challenges of our time. It all started in 1988 when the IPCC (Intergovernmental Panel on Climate Change) was formed, where the risk of human-induced climate change was assessed for the first time. This was followed by the World Summit in Rio in 1992. And the adoption of the United Nations Framework Convention on Climate Change (UNFCCC), COP 3 Kyoto Protocol in 1997, COP 15 Copenhagen in 2009, COP 17 Durban Platform in 2011, Doha Amendment 10.01.2011.

By adopting the Paris Agreement in 2015, the international community committed to limiting the increase in global average temperature to below 2°C, with the aim of keeping it below 1.5°C compared to the pre-industrial period. In response to these commitments, the European Union has defined climate policy through the European Green Deal, a strategic framework aiming to achieve climate neutrality by 2050. As a result of the Green Deal, the EU has adopted the Fit for 55 legislative package, which envisages a reduction of greenhouse gas emissions by at least 55% by 2030. One of the key mechanisms of this package is the Carbon Border Adjustment Mechanism (CBAM), which aims to prevent carbon leakage and ensure a level playing field between EU producers and those from third countries that do not have equally stringent climate policies.

The CBAM is an innovative regulatory instrument that gradually introduces the obligation to calculate and report CO_2 emissions for certain categories of imported products, including steel and aluminium, in subsequent stages and the obligation to purchase CBAM certificates. This paper focuses on the analysis of key elements of CBAM reporting for steel and aluminum products, and discusses the challenges and implementations for private entities exporting to the European Union market.

2. CBAM – regulatory framework

The Carbon Border Adjustment Mechanism (CBAM) is a regulatory framework of the European Union aimed at reducing carbon dioxide emissions for certain products, including steel and aluminum. The aim of the CBAM is to ensure a level playing field in the market between producers within the EU, who are already subject to stricter climate regulations, and producers from third countries. Regulation (EU) 2023/956 of the European Parliament and of the Council, adopted on 10 May 2023, lays down the Carbon Border Adjustment Mechanism.

The CBAM regulation looks at CO2 emissions, but on a much smaller scale than the Carbon Footprint and GHG Protocols (greenhouse gases) applicable in the European Union. Therefore, CBAM carbon emissions refer to:

- Input material within the CBAM (in the case of complex products)
- CO2 emissions resulting from the production of CBAM products at the industrial plant level
- Electricity consumed for the production of CBAM products

The category of goods subject to CBAM is defined by the list of CN codes and the CBAM Regulation. It should be noted here that for complex products, it is necessary to consider the input quantities of products falling under the CBAM Regulation, even if that product is not characterized as a product of the 6 branches referred to in the CBAM Regulation.

3. Scope of the CBAM Regulation

Under the Carbon Border Adjustment Mechanism (CBAM), the European Union requires carbon emissions to be reported and accounted for on imports of products from high-emission sectors. The Harmonized System, an international trade classification system, is used to accurately identify goods.

The table below shows some of the products currently covered by the CBAM regime during the transitional period (2023–2025), along with their tariff codes.

Table 1. CBAM Products and associated tariff numbers

Sector	Product description	Tariff numbers
Steel	Iron or steel products [a]	7205, 7208 – 7217, 7219 – 7223, 7225 – 7229, 7301 – 7311, 7318 i 7326.
Aluminum	Aluminum products	7603 – 7608, 7610, 7611 00 00, 7612, 7613 00 00, 7614, 7616

[a] *This collective category of goods includes semi-finished and finished products.*

4. Emissions calculation

Reducing companies' CO2 emissions is part of the solution to climate change, with carbon neutrality as the long-term goal. This reduces greenhouse gas emissions, making it easier to meet commitments under international agreements and achieve climate neutrality in Europe by 2050. As an interim solution, the European Commission has adopted the CBAM Regulation, the CBAM Implementing Regulation and defined a format for submitting CO2 emissions data to the CBAM registry.

CO2 emissions are calculated or estimated using activity data (such as the amount of fuel used) and relevant emission and conversion factors (e.g. calorific values). These factors allow companies to calculate CO2 emissions from a range of activities, including energy use, waste disposal and recycling, and production-related transport activities.

The calculation of CO2 emissions includes three categories:

- Direct CO2 emissions: CO2 emissions resulting from the production of the product in question under the control of the company,
- Indirect CO2 emissions: emissions from the production of purchased energy used by the company (electricity, heat or steam),
- Other indirect CO2 emissions: emissions from employee business travel, transport of products and materials, waste generated by the organization, etc.

CO2 emissions are defined as Scope 1, Scope 2 and Scope 3 emissions.

Emissions reported in Scope 1 are:

- Direct emissions from stationary energy sources
- Direct emissions from mobile energy sources
- Direct emissions from production processes

Scope 2 includes indirect CO2 emissions that occur outside the company's locations and are related to the purchase and consumption of electricity, heat or cooling energy:

- Indirect CO2 emissions due to the consumption of electricity from the network
- Indirect CO2 emissions due to the consumption of heat and cooling energy from an external source

Scope 3 CO2 emissions occur from sources owned or controlled by other entities. The most significant CO2 emissions are associated with the input and output flows of materials used in production:

- Materials used for production (origin of materials)
- Quantity of finished product placed on the EU market
- Quantity of waste materials

4.1 Direct CO2 emissions - Scope 1

In calculating the CO2 emission factor for fossil fuels (petroleum derivatives), in addition to direct combustion emissions, emissions arising in the production process in oil fields, during transport to refineries, during oil processing in refineries, and due to the transport of petroleum derivatives to the point of consumption are added.

The determination of the CO2 emission factor is shown using the example of diesel fuel. The average calorific value of diesel fuel is 42.71 MJ/kg [2], and the emission factors due to the combustion of diesel in road transport are 74.1 kg/GJ for CO2.

Direct CO2 emissions from the combustion of gaseous fossil fuels (natural gas and compressed natural gas) are increased due to emissions during the transport and distribution of natural gas to the point of consumption.

The determination of the CO2 emission factor is shown using the example of natural gas used in stationary energy sources. The average calorific value of natural gas is 34.60 MJ/kg, and the emission factors for the combustion of natural gas are 56.1 kg/GJ for CO2.

Specific embedded direct emissions (SEE direct) refer to CO2 emissions that are directly emitted from the production process of a specific product. This term covers CO2 emissions that are directly linked to specific stages of the production process.

The calculation of SEE (direct) typically involves the following steps:

- Identification of direct emission sources:
    - Combustion of fuels for energy or heating in the factory,
    - Emissions from chemical processing processes,
    - Emissions during transport within the facility.
- Collection of energy and fuel consumption data for each CO2 emission source:
    - Amounts of fuel or energy consumed,

- Types of fuels used (e.g. natural gas, coal, oil).

- To calculate emissions, appropriate emission factors are applied, which represent the amount of emissions per unit of fuel (e.g. kg CO2 per liter of oil or cubic meter of gas). These factors can be specific to the type of fuel or process, and are often provided by international agencies such as the IPCC (Intergovernmental Panel on Climate Change) or national environmental standards.

4.2. Indirect emissions – Scope 2

This category includes the determination of emission factors for electricity consumption in a particular country. The electricity consumed is mostly produced in Serbia/Bosnia and Herzegovina, and to a lesser extent imported. The structure of electricity production consists of renewable energy power plants (hydropower plants, more recently also photovoltaic solar power plants), thermal power plants (coal, more recently natural gas). On the other hand, electricity imports are supplied from imports.

In Serbia, the Regulation on final energy conversion factors into primary energy and carbon dioxide emission factors ("Official Gazette of the Republic of Serbia", No. 111/2021 and 6/2023) is in force, from which it can be seen that the emission factor for electricity supplied by organizations from the Elektroprivreda Srbije system is 1.099.

For other countries in the EU and outside the EU, it is presented in a table in the databases recommended by the European Commission.

4.3 CO2 emissions arise from sources under the control of other entities - Scope 3

These CO2 emissions are linked to materials incorporated into products placed on the EU market, so-called precursors.

Scope 3 emissions cover a wide range of activities, largely including emissions from the supply chain. In order to calculate CO2 emissions, it is necessary to have data on:

- raw materials, manufacturer name and location,
- waste material from the above raw materials,
- products delivered with incorporated materials to the EU market.

These emissions are often the most complex to measure, but can represent the largest part of a company's total emissions. The impact factors for direct and indirect emissions incorporated into precursors can be found in databases recommended by the European Union.

The methodology for calculating the CO2 emission factor is specific for each category.

Total CO2 emissions are reduced to equivalent carbon dioxide emissions (CO2 eq). And as such are reported within the report.

Every exporter to the EU, who exported CBAM goods during a given quarter of the calendar year, must submit a CBAM report for that quarter containing information on:

1. the total quantity of CBAM goods exported,
2. the actual total direct and indirect emissions embodied in the goods, and
3. the carbon price already paid in the country of production for the emissions embodied in the imported goods, taking into account any rebates or other forms of compensation available.

5. Transition phase

Transition period The CBAM has a transition period starting on 1 October 2023 and lasting until 31 December 2025, the purpose of which is to collect data to fine-tune the design of the CBAM with a view to its definitive phase of implementation from 2026.

The aim of the transition period is to serve as a pilot and learning period for all stakeholders (importers, manufacturers and authorities) and to collect useful information on embedded emissions in order to refine the methodology for the final implementation period. During the transition period, the obligations of exporters to EU countries will be limited to reporting only, without paying any financial adjustment and without the need for verification of the report by an accredited verifier.

In May 2025, the European Commission adopted the so-called Omnibus I, which brings some simplification of the mechanism.

The novelties relate to:

- New threshold of 50 tonnes: Exemption of ~90% of importers by number — but still covering 99% of emissions.
- New compliance deadline: The financial phase is moved to 2027, giving companies additional time to prepare.
- Smarter reporting and lower penalties: Flexible quarterly obligations (reduction of coverage from 80% to 50%) and greater clarity on penalties.
- Recognition of carbon taxes paid outside the EU: Attributing carbon costs already paid abroad, encouraging broader climate cooperation.

Although the proposal has been adopted at technical level, it has not yet entered into force, as the formal alignment procedure with the European Parliament is ongoing. Final adoption and publication are expected in the coming months.

6. Conclusion

The CBAM is one of the key instruments of the European Union's climate policy, with effects that go far beyond the borders of the Union. For non-EU countries, especially those with developed steel and aluminum industries, this mechanism brings significant challenges, but also opportunities.

The challenges are reflected in increased export costs, the need for accurate and verified emissions data, as well as the potential loss of access to the European market. However, at the same time, the CBAM can serve as a catalyst for structural reforms, accelerated decarbonization and the transition to greener technologies.

Countries that recognize the importance of this regulatory framework in time and invest in the capacity to monitor and report on emissions can not only maintain their competitiveness but also position their industry as a reliable partner for European companies. In this context, the CBAM is not only a mechanism for protecting the EU's climate policy, but also a call for transformation for all actors in international trade.

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Application of optimization methods in manufacturing companies

Vera Tarlać and Mara Savić

Agency "TQ Net Consulting", Trg zlatnih ljiljana 29, 71000 Sarajevo

E-mail: office@tqnet-consulting.com

Abstract. This paper analyzes the application of various optimization methods in manufacturing companies with the aim of improving efficiency, reducing costs and increasing productivity.
The focus is on methods such as Value Stream Mapping - VSM, 5S and Six Sigma, which enable the identification and elimination of bottlenecks in production processes. Using case studies and data analysis, the effects of the application of these methods in metal processing companies were investigated.
The application of Lean methodology in order to optimize production processes in the metal industry shows that by using tools such as VSM (Value Stream Mapping) and the 5S method, key inefficiencies in the production process can be identified.
The results show that the application of Lean principles reduces the production cycle time by 25% and increases productivity by 18%. These results confirm the importance of the Lean approach in improving the efficiency of industrial processes, and show that systematic optimization leads to a significant reduction in cycle time, optimization of resources and an increase in product quality.
Based on the findings, recommendations were proposed for the implementation of optimization strategies in manufacturing companies in order to achieve sustainable improvements.

1. The Basics of Lean Methodology

Lean methods are a set of principles and techniques aimed at eliminating waste and continuously improving business processes[1]. These methods originate from the Toyota production system and are now used in various industries.

The basic principles of the Lean methodology are:

- Defining value – Understanding what the customer really values and eliminating activities that do not add value,
- Value Stream Mapping – Analysis of all steps in the process to identify and eliminate wastes,
- Smooth flow of materials and information – Process optimization to eliminate delays and interruptions in work,

- Withdrawal – Production or delivery of only what is needed and in the quantity that is needed, in order to reduce inventories and losses,
- Striving for continuous improvement (Kaizen) – Continuous improvement of the process through small but constant changes.

Since Lean methods are aimed at eliminating waste, it is desirable to define the most common types of waste that are successfully solved:

- Overproduction – More is produced than necessary
- Stocks – Holding too many stocks that tie up capital
- Movement - Unnecessary movement of workers or equipment
- Transport – Unnecessary movement of materials or products
- Waiting – Wasting time due to delays in processes
- Overprocessing of materials and information
- Defects – Errors that lead to refinishing or scrap

To overcome problems and reduce dissipation, various Lean methods and tools are used.

As in all well-ordered systems, and in accordance with the Deming circle, it all starts with planning. A lean plan differs whether it is production or services, it also differs from the type of production, whether it is serial or individual production.

The Lean Plan consists of several phases:

- An analysis of the current situation,
- Elimination of waste and increase efficiency, and a list of Lean tools that can be applied and that solve a specific problem that has been identified,
- Implementation of selected Lean tools in production,
- An assessment of the expected results and benefits.
- Dynamic Implementation Plan with Deadlines and Responsibilities

2. Value Stream Mapping - VSM

Value Stream Mapping (VSM) is a tool used within the Lean methodology to visually display all the activities involved in the delivery of a product, from start to finish. The goal of VSM is to identify and eliminate losses in processes, in order to improve efficiency and increase value for the customer.

VSM displays: the physical flow of materials, the flow of information, all activities in the process, with data on Cycle Time, Waiting Time, Value-Added Time, number of workers engaged, quantity, inventory, etc.

The key goals of VSM are: to determine the difference between value-adding activities and those that do not, to find production bottlenecks: downtime and redundancies, to create an improved version of the flow [2].

The use of Value Stream Mapping (VSM) involves a few basic steps while respecting the principles:

- selection of processes or products – choose one value stream, and not all at once,

- team formation – involving employees from different functions that are part of the process,
- On-site data collection and mapping of the actual flow, creation of the existing state of the process,
- analysis and identification of gibbits,
- A proposal to improve the value stream,
- action plan and implementation,
- Monitoring and continuous optimization.

2.1 An example of the application of VSM in a manufacturing company

The case study refers to a typical cycle from customer order to delivery: The customer sends the order → the planning department → material procurement → cutting → welding → painting → quality control → delivery.

VSM will show:

- Where there is a downtime (e.g. waiting for materials)
- How long does each step take,
- Where the stocks are formed,
- Which steps add value to the customer and which don't.

Identifying the problem with a practical example refers to:

- The procurement lasts 2 days, the warehouse does not clearly define the minimum stock - the dissolution is Waiting for materials → the solution of this problem by applying the Lean method - Just-In-Time.
- Excess stock of finished welded elements for assembly - waste of space and impact on product quality due to inadequate storage, increase in costs due to protection in intermediate storage → solution to this problem - Reduction of storage through the Pull system.
- Defects and rework, the control found that 12% of the pieces were made with a mistake, of which 5% can be reworked, and 7% is scrap – it is a matter of the distribution of costs in terms of materials and finishing time→ The solution to this problem - Poka-Yoke systems for error prevention.
- Inefficient use of labor, schedule of workplaces, tool warehouses and inter-phase warehouses of such a schedule that requires constant movement of workers, transport of materials by internal transport, waiting for workers for the next operation – Wasting costs, wasting time, wasting labor energy... → solution to this problem is Lean layout and standardization.

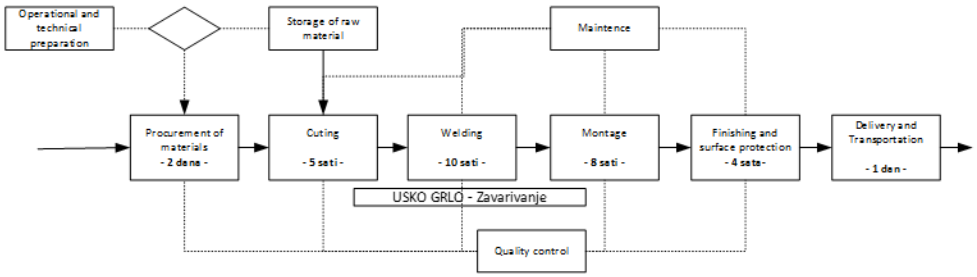

Figure 1. An example of value stream mapping in the production of metal structures.

In the above example, the biggest dissipation is obviously the waiting for the procurement of materials, the excess stock of finished welded elements for assembly, then the costs in terms of materials and finishing time, and the inefficient use of labor, the arrangement of workplaces, which resulted in the welding operation being a bottleneck in this value stream.

Thus, compared to the seven types most commonly encountered in production plants as shown in Table 1, it is observed that all the wastes observed in the observed company are typical.

Table 1. The Seven Types of Most Common Wastes in Production

Waste	Solution
Excessive production	Just-In-Time
Inventory	Lean Sourcing & Warehouse Optimization
Waiting	Automatic work order scheduling and tracking
Internal transport	Better organization of the workspace
Moves	5S methodology for efficiency
Error	Poka-Yoke Error Prevention Systems
Unused Workforce Potential	Standardized Work Procedures and Training

3. The 5S method

5S is a Lean method originating in Japan, used to organize and standardize workspaces to increase efficiency, productivity, and safety.

The name 5S comes from five Japanese words that begin with the letter "S," as shown in Figure 2.

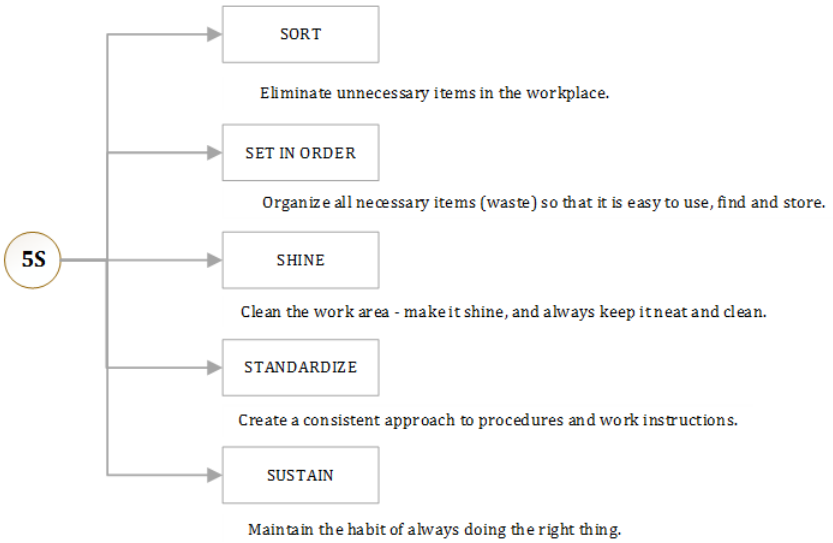

Figure 2. Graphical representation of the 5S methodology.

The application of the 5S method aims to eliminate waste of time and excessive consumption of resources, increase productivity and quality of work, improve safety at work, better motivation and employee satisfaction.

It is often noted that the 5S method is used exclusively for the decoration of the work area, especially in production organizations. However, the experiential contribution of the method in solving waste when working on a computer is poor organization of the desktop, poor organization of space on the server, which results in a waste of time searching for the necessary information or documents.

However, the greatest benefit of the application of 5S is in manufacturing companies, where the analysis of the situation often shows that certain warehouses, materials and tools used are located in an inadequate place, so that a lot of time is wasted on the delivery of the workpiece or the provision of tools. On the other hand, workplaces that are overloaded with unnecessary materials or documents, in addition to not being safe to work with, waste time looking for certain elements to work on activities that contribute to the increase in value.

This simple method is practiced very often in the process of optimizing the process in accordance with the implementation plan.

4. Six Sigma Method

Six Sigma is a process improvement methodology used to reduce variation and defects in production, with the ultimate goal of increasing product quality and process efficiency. It was developed by Motorola in the 1980s and was later widely used in industries around the world, especially in manufacturing sectors.

Six Sigma is an integrated approach to optimization that combines statistical methods with systemic quality management. In the context of a manufacturing company, Six Sigma stands out in particular as a method that can bring measurable and long-term benefits, through the systematic identification and elimination of the causes of variations in processes.

The goal of this Lean method is to achieve a level of process quality in which less than 3.33... defects per million opportunities (DPMO) are recorded. This allows for a high degree of accuracy and stability of production processes.

The Six Sigma methodology is usually implemented through a structured DMAIC cycle:

- Define – Identify the user's problems, goals, and requirements.
- Measure – Collecting data and measuring the current efficiency of a process.
- Analyze – Analyze data to identify the causes of problems and variations.
- Improve – Development and implementation of solutions that eliminate the root causes of problems.
- Control – Introduction of a control system to ensure the long-term sustainability of improvements.

A variety of tools are used within the DMAIC cycle, including:

- SPC (Statistical Process Control)
- Pareto analysis
- Ishikawa (Fishbone) diagram
- FMEA (Failure Modes and Effects Analysis)
- Process Mapping

The main advantages of using Six Sigma in a manufacturing company are:

- Reducing waste and quality costs
- Increasing customer satisfaction
- Greater production efficiency
- Improving internal processes and organizational culture.
- More accurate decision-making based on data

4.1 Practical example: Production of metal structures

A company that produces steel halls supplies prefabricated structures for industrial facilities is observed. Over the past 6 months, clients have reported on several occasions that the I-gauges did not fit properly on the mounting points, causing additional costs and delays on site.

This complaint points to problems in the accuracy of dimensions and positioning of mounting holes. The company decides to apply the Six Sigma methodology to identify and eliminate the causes of the problem.

The analysis showed what the identified problem is and the goal of this methodology

- Problem: Mismatch of holes on the I-profiles with the mounting points.
- Goal: Reduce the number of defective elements to less than 1% within 2 months.
- Tool: The SIPOC diagram(Supplier–Input–Process–Output–Customer) is used to map the process and all its participants.

Data from the production line was collected: 500 I-profiles were produced in the past 30 days and it was found that 8% had a deviation of more than 5 mm in the position of the holes. When collecting data, the checklist tool and histogram were used, where the checklist records the number and type of defects, the histogram shows the frequency of deviations.

The analysis of the causes was carried out through the Ishikawa diagram (Fishbone) and the Pareto diagram. When creating the Ishikawa diagram, potential causes were analyzed:

- People: differences in the handling of measuring tools
- Machines: wear of hole drilling milling machines
- Methods: the absence of a standard procedure for positioning the profile
- Material: bending due to improper storage
- Measurement: use of different meters (uncalibrated)

The Pareto diagram shows that 72% of errors are due to inaccurate positioning prior to drilling, which becomes a focus for improvement.

On the basis of the analysis, measures were adopted to improve the process:

- Templates for profile positioning have been introduced, using the Poka-Yoke quality tool
- The measurement method was standardized and a control point was set immediately after drilling.
- Workers trained for the new procedure.

The next step is to establish monitoring and control for the sustainability of the applied model. The SPC (Statistical Process Control) tool was used, which is defined to monitor the position of holes in the sample of every 10th profile using the X-bar and R maps. The FMEA (Failure Mode and Effects Analysis) method has also been introduced to provide an assessment of the risk of failures in the positioning and drilling process. A control plan has also been set up for the maintenance of templates and calibration of measuring tools every 30 days.

With the regular implementation of the defined measures, after 2 months, the following results were achieved:

- The proportion of defective profiles decreased from 8% to 0.6%.

- Reduced debugging costs on site.
- Higher customer satisfaction and shorter installation times.

Through this concrete example of steel hall production, it is shown how the Six Sigma methodology and quality tools (Ishikawa, Pareto, SPC, FMEA, Poka-Yoke, etc.) can directly contribute to the elimination of errors, reduce costs and improve the reputation of the company. The integration of these tools into everyday operations is the basis for the continuous improvement of quality and competitiveness in the metal construction sector.

5. Conclusion

The analysis and practical application of Lean methodology in metal manufacturing companies has confirmed that the systematic application of tools such as Value Stream Mapping, the 5S method and the Six Sigma approach significantly contributes to the elimination of waste, resource optimization and increased product quality. Case studies show that, through the identification of bottlenecks and process standardization, measurable results are achieved, such as reducing the duration of the production cycle, increasing productivity and reducing the number of defective products.

In addition to the direct benefits in terms of reducing costs and increasing efficiency, the introduction of Lean tools also contributes to strengthening organizational culture, improving customer satisfaction and increasing competitiveness in the market.

Although the research results are limited to specific case studies in the metal processing industry, the findings indicate the possibility of wider application of Lean methodology in other industries, while adapting to the business context. Future research may be focused on the integration of Lean methods with digital technologies and the principles of Industry 4.0, which would open up space for additional improvements and sustainability of production systems.

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Establishing an institutional culture of quality in higher education

Esad Bajramović[1], Fadil Islamović[1] and Ahmet Žalić[2]

[1] University of Bihać, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina
[2] BE Consulting, Bihać, Bosnia and Hercegovina

E-mail: bajramovic_e@yahoo.com

Abstract. The main reason for writing and publishing this paper is to highlight the importance of implementing a quality culture in higher education. Establishing an institutional quality culture in higher education requires a comprehensive approach that includes strategic planning, engagement of all stakeholders, and continuous improvement. Higher education plays an important role in the development of every society. Education is one of the fundamental pillars of society. The institutional culture of quality is the most important level of culture in higher education. Essential characteristics, structure, topology, strength, and internal and external aspects determine its manifestation. A serious insight into the state of higher education institutions in Bosnia and Herzegovina shows that the institutional culture in higher education is the subject of interest of numerous quality management managers, as well as the management of higher education institutions. Consequently, the authors decided to conduct a public debate on this very important topic. Quality culture in higher education, as a narrower term, is an important element of the culture of higher education and means the integration of TQM principles. The starting point of all efforts to implement and improve institutional culture is business success. In this context, a culture of quality as part of the culture of higher education represents an instrument for managing business performance.

1. Introduction

In today's dynamic educational environment, higher education is faced with numerous challenges that require continuous process improvement in order to achieve excellence in teaching, research, and administration. The establishment of an institutional culture of quality is the basis for ensuring a high level of educational services, which is particularly important in the context of the modernization of higher education institutions. The paper aims to investigate the methods and mechanisms by which a quality culture can be established and maintained in institutions of higher education, with special reference to the application of normative frameworks and guidelines that have been developed to meet the requirements of internal and external quality management systems [2].

Contemporary higher education faces numerous challenges that require constant improvement of the quality of the academic process, research, and management. In this context, building and nurturing an institutional culture of quality in higher education is a key element for achieving long-term excellence and specificity of higher education institutions, which presents the path towards TQM.

Through the review of the literature and an analysis of well-established quality management models, the paper will address the key elements of establishing an institutional quality culture and provide specific guidelines for implementation in practice. The paper will refer to documents and recommendations from Bosnia and Herzegovina, the country that has experienced a significant transformation in the approach to quality assurance through the Bologna process [3].

Institutional quality culture is not only the formal fulfillment of standards and procedures, but also implies a collective way of thinking, behavior, and action of all members of the academic community, focused on the TQM model. Its successful implementation depends on a clear vision of the management, the involvement of all actors of teaching and non-teaching staff, students, and the wider community, and the existence of a system that encourages responsibility, evaluation, and reflection.

2. The significance of the institutional culture of quality in higher education

Institutional culture of quality implies a set of values, norms, and procedures that a higher education institution applies in its daily work to ensure a consistent standard of educational services. It is not only a technical process, but a comprehensive concept that includes strategic planning, constant evaluation, transparency of working procedures, and focus on continuous improvement. The basis of such a culture lies in the active involvement of all members of the institution - from management to teaching staff to students - in a joint effort to achieve excellence.

Unlike formal quality management mechanisms, which are often aimed at examining the requirements of external accreditation bodies by the Agency for the Development of Higher Education and Quality Assurance of BiH, the quality culture implies internal motivation and dedication of members of the academic community. It is a dynamic process in which quality is not perceived as a final goal, but as a constant obligation and responsibility for meeting the requirements of the ISO 9001, ISO 14001, ISO 45001, ISO 26000, ISO 31000, and ISO 22301 standards.

The significance of the institutional quality culture is reflected in its impact on:

- Academic excellence promotes teaching methods based on learning outcomes and research work focused on solving specific problems.
- Organizational development contributes to efficient management and better coordination between organizational units.
- Involvement of students encourages the active participation of students in the evaluation of classes and decision-making by the academic council and senate of the university.

- A reputation of trust builds a positive image of the institution among students, employers, and other interested parties.

Therefore, building a culture of quality is not only a strategic need but also a fundamental value that determines the identity and long-term success of a higher education institution.

Institutional culture of quality, therefore, implies flexibility and the ability to respond to new challenges, which enables educational institutions to be competitive and innovative.

3. Framework for excellence in higher education

The theoretical framework for establishing and maintaining a culture of quality in higher education was formed through numerous international initiatives, one of the most significant in Europe being the Bologna Process. Documents such as ''Manual for quality assurance'' and ''Standards and guidelines for quality assurance in higher education'' (developed with the support of relevant ministries and international organizations) provide the basis for establishing a comprehensive system of qualifications within institutions [3]. These documents emphasize the importance of defining the institution's mission, vision, and values and provide guidelines for building internal and external quality assurance systems.

Normative frameworks applied in Bosnia and Herzegovina, which are harmonized with European standards, emphasize the need for transparent and responsible management procedures of higher education institutions. Such frameworks enable comparability, constant monitoring, and evaluation of the work system, which directly contributes to the establishment and improvement [3].

The establishment and development of an institutional quality culture cannot be observed in isolation, but in the context of a broader quality management framework that includes normal strategic and operational aspects. This framework includes international standards, national laws, and regulations, as well as internal mechanisms of the higher education institution.

Establishing quality internal systems is the foundation of any institutional quality assurance system. This includes establishing clear methodological approaches, defining criteria for evaluating teaching and administrative activities, and introducing regular internal audits. The institution should develop internal procedures that ensure that all processes are constantly reviewed and improved in order to maintain the high level of quality reached. Application of pre-defined procedures, such as evaluations of study programs and evaluation of teachers and analysis of student results, enables the identification of weak points and their systematic development.

One of the key elements of success is the involvement of all stakeholders within the institution, from administration to students. The implementation of the feedback system and the use of surveys and evaluations ensure that changes are based on the real needs and expectations of users of educational services. Such an approach contributes

to the creation of an open and stimulating institutional climate in which the aspiration for continuous improvement is naturally integrated into everyday work.

3.1 The role of leadership and vision

Leadership in higher education institutions plays a decisive role in establishing an institutional culture of quality. Management must actively promote quality values and set clear visions and goals that are in line with the institution's mission. Inspiring and transparent leadership can motivate its employees to accept changes and continuously strive to improve educational activities. It is important that leaders lead by example and ensure that everyone involved understands the importance and continuous development of the quality system.

Higher education institutions must respect high business morals and ethics. Leadership based on responsibility for establishing an institutional culture of quality obliges management to fulfill legal and ethical requirements and manage risk factors, as an integral part of performance and improvement management. A higher education institution must fulfill the requirements of ethics and morals if it deals with processes that make sense and realizes the processes of teaching, scientific research work, and knowledge transfer under conditions of equal policies for everyone, including teaching staff and researchers, without using the conditions of monopoly and protectionism.

Social responsibility implies the fulfillment of all legal obligations related to the management of business processes, as well as requirements (technical and professional) related to the characteristics and professional processes of business. The observance of the Framework Law on Higher Education in Bosnia and Herzegovina is particularly noteworthy. This implies that all other lower-level laws must be harmonized with the Framework Law on Higher Education in BiH.

Business ethics includes a set of ethical principles, values, and norms that guide the behavior of teaching and administrative staff of higher education institutions in a business environment.

The key elements that business ethics include are: honesty, fairness, responsibility, respect for the law, protection of student interests, care for employees, environmental protection, anti-corruption behavior, fair treatment of competition, and social responsibility.

Social responsibility towards employees is reflected in respecting high ethical standards that include humane working conditions and respect for the human rights of employees [5].

In addition, business ethics and morality imply that a higher education institution maintains constant awareness of the potential impacts of its students and the work environment on environmental protection, safety, and human health, which refers to its relationship with society.

The academic community, in accordance with its possibilities, material and human resources, should go beyond legal obligations. This implies constant improvements in

all processes. When there is a change in management, it is necessary to review the management and evaluate the system. In this way, it is possible to identify inconsistencies and make an action plan for alignment with the Framework Law on Higher Education in BiH.

Special attention should be paid to fulfilling legal obligations when advancing to higher positions. It must not be allowed for cantonal laws to be changed without being in accordance with the Framework Law on Higher Education in BiH.

In addition to formal leadership, management must provide informal support through the development of professional networks, workshops, and training that encourage the adoption of new knowledge and work methods intending to improve teaching and management processes. A clearly defined strategy that includes short-term and long-term development goals enables institutions to adapt to changes in the educational environment and develop cultural foundations for meeting high-quality standards.

3.2 Rector's authority

A rector with high authority carries with him several important values that are crucial for the successful management of a higher education institution. These values include: responsibility, integrity, justice, vision, competence, authoritativeness, openness to dialogue, transparency, empathy and respect, and dedication to education and science.

The management of the university, headed by the rector, would have to adopt certain methods and tools to help improve the process. It is necessary to carry out planned training of all employees who participate in management and make important decisions at a higher education institution. This plan includes the training of people by function, rector, vice-rectors, deans, vice-deans, department heads, the institute director, and quality assurance representatives.

The concept of institutional culture of quality requires the application and implementation of total quality. It offers a methodology for establishing a balance in meeting the expectations of all interested parties and aspects of social responsibility and sustainable development of a higher education institution. A social climate must be created in which interested parties will have influence in the Management Boards when making strategic decisions, in order to ensure the social responsibility of the higher education institution.

The best way to completely revitalize a higher education institution is to apply the concepts of TQM and excellence, because it will enable it to establish new curricula and programs, and new projects in accordance with the needs of the economy and society. In order for the concept of excellence to be successfully applied, it is necessary to analyze different management approaches [5]. The analysis is presented in Table 1.

A higher education institution must have an efficient and effective organizational structure, which ensures the maximum use of all resources, materials, and humans. The new concept must meet the requirements of standardized management systems. For

the above reasons, the rector must request the management to master and implement certain tools and methods, i.e. new techniques. A continuous exchange of experiences between management structures should be planned.

Table 1. Elements of the culture of transition in higher education

Element	Our approach (traditional)	Classical approach	Excellence approach
Management style	– "The Rector decides everything." – "Professor has the authority."	– plan – organize – delegate – control	– PDCA (Plan-Do-Check-Act) – Communicate – Include all levels: students, assistants, professors – Objective decision-making – Building an academic quality culture
University objectives	– "Issue diplomas, earn tuition fees" "Enroll as many students as possible."	– education and research – academic reputation	– satisfaction of students and employers – continuous improvement of the quality of education – social responsibility and innovation
Academic culture	– "We are the elite." – "Students can manage on their own."	– hierarchical and departmental structure	– team and process orientation – inter- and multidisciplinary cooperation – involving students in processes
Motivation	– "If you don't want to, there's someone who will."	– awards for publications – academic status	– motivation through career development – recognition of teamwork – Improvement of teaching and scientific work
Quality	– "We have accreditation, so everything is ok." – "Papers are sorted."	– compliance with standards – evaluation per request	– constant improvement of the teaching process – regular student evaluation and feedback – quality in all segments: teaching, research, support
Problem solving	– "It's the student's fault"	– ad-hoc problem solving	– systematic approach to problem solving

	– "That is not my job''	– individual approach	– involvement of all stakeholders – problems as an opportunity for improvement
Relations with students	– "Students are numbers" – "It's important that they pay""	– meeting basic needs – formal communication	– partnership with students – active listening and dialogue – involvement of students in decision making processes

4. Challenges and recommendations for implementation

Despite the recognized importance of institutional quality culture, its development is often faced with numerous challenges that can slow down or limit progress. These challenges stem from structural, organizational, and human factors and require a strategic approach to overcome them.

- Resistance to change

One of the most common challenges is employee resistance to new practices and evolutionary mechanisms. A quality culture through the application of established patterns of behavior often causes uncertainty, doubt, or a sense of threat in individuals.

- Formalism and bureaucracy

There is a risk that the quality system is reduced to meeting administrative requirements, without real commitment to quality goals. This approach results in the so-called Culture of form, where reports and procedures are only formally present, without affecting concrete improvement.

- Lack of motivation

Without a clearly defined benefit for the individual and the collective, members of the academic community may experience quality activities as an additional burden. Insufficient information and education about the purpose and significance of quality can often lead to passivity and superficial engagement.

- Limited resources

The introduction, implementation and maintenance of the quality system requires certain human, technical and financial resources. Lack of support in these aspects can seriously threaten the institution's concept of developing and improving a quality culture.

- Insufficient involvement of students

Although students play a key role in the quality system, in practice, they are often marginalized or included only formally. Their experiences and perspectives remain insufficiently used, which diminishes the effect of evaluation processes and reduces trust in the system.

5. Basics for building and strengthening the culture of quality

The development of an institutional culture of quality requires a strategic approach, continuous engagement, and clearly defined measures that empower all members of the academic community. The recommendations that can contribute to strengthening the culture of quality are presented below:

- Strengthening leadership and quality vision

The management of the institution must be the bearer of the quality vision, with a clear commitment and consistent implementation of the policy that promotes the European EFQM excellence model. Leaders should be role models in promoting the value of quality and encourage a culture of dialogue, trust, and participation. When strengthening leadership, it is necessary to carry out TQM and EFQM education.

The EFQM model is used to assess and improve the overall business excellence of the university. The EFQM model is based on the principles of quality management and is often used as part of integrated quality systems.

- Education and empowerment of employees and students

Systemic education on quality concepts and tools should include all employees and students. By strengthening their role in the processes of planning, evaluation and improvement, a sense of shared responsibility and belonging is created.

- Integration of quality into processes

Quality-related activities must not be separated from daily work. It is necessary that every process, from teaching and scientific research work to administrative support, be guided by the principles of quality. This implies constant improvement, reflection, and self-assessment.

- Developing the internal audit system

Internal audit must be a continuous process that does not only serve formal goals, but also provides a realistic insight into the state of the institution's needs. The results of internal audits should be used for decision-making, planning and corrective measures. It is a chance for improvement.

- Support for innovation and good practices

Institutions should recognize and reward innovative approaches in teaching, scientific research, management, and student support. Good practices should be documented, shared, and used as a model for other organizational units.

- Active involvement of students

Students must have a real role in structures that deal with quality, not only as respondents, but as members of the University senate, quality assurance teams, commissions, councils, and improvement teams. Their perspective brings reality and relevance to the measures being implemented.

6. Conclusion

Establishing an institutional culture of quality in higher education is a long-term and complex process that requires strategic leadership, collective dedication, and continuous work on improving all segments of academic activity. Only through the development of such a culture is it possible to achieve true academic excellence, educational relevance, and competitiveness in the global knowledge market. The analysis of the concept of a normal framework of key elements and challenges clearly shows that a true quality culture is possible only if there is a clear vision, strong and responsible leadership, and willingness to learn, cooperate and self-evaluate. The active involvement of teaching and administrative staff, as well as students, is key to creating an environment in which quality is perceived as a common goal and a permanent value.

The recommendations presented in this paper indicate the need for a strategic approach, education, improvement of internal processes and encouragement of innovative solutions. Investing in a culture of quality should be considered as an investment because it not only contributes to academic excellence but also strengthens the social role of higher education as a basis for the development of knowledge, ethics, and responsible citizenship.

The concept of quality 5.0 represents a new development phase in the approach to quality, which goes beyond technical and administrative aspects, emphasizing the balance between technology and people. In higher education, this model brings a potential transformation through the introduction of personalized learning, the use of artificial intelligence, as well as strengthening the role of ethics, empathy, and social responsibility. Quality 5.0 is especially present in developed countries, while most higher education institutions are still between models 3.0 and 4.0. The introduction of quality 5.0 requires a strategic approach, strengthening of digital infrastructure, continuous education of teaching staff and strengthening of student voice in the process of quality assurance, which is the excellence that awaits us in the period from 2026 to 2030.

Quality 5.0 in higher education requires a transition from formalism to the values of education that is inclusive, sustainable, technologically empowered, ethical, and socially useful. It is a call to universities to be not only institutions of knowledge, but agents of change in society.

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Revitalization of company business

Ahmet Žalić[1] and Esad Bajramović[2]

[1] University of Bihać, Faculty of Technical Engineering, Bihać, Bosnia and Herzegovina
[2] BE Consulting, Bihać, Bosnia and Hercegovina

E-mail: bajramovic_e@yahoo.com

Abstract. It is well known and confirmed in practice that there is almost no company that does not experience a crisis and the need to invest in its survival during the period of its operation. In most cases, this happens to them in the maturity phase/peak of their business. Companies, as well as products and processes, have their own life cycle. In a state of crisis or a state in which the company has slow growth or cessation of growth, as well as a decline in business effects and effects, its revitalization, i.e. the revitalization of its business, is necessary. The purpose of the revitalization process is to extend the company's operations, enable growth and development and achieve business success. This paper will deal with revitalization procedures or steps that must be taken. The start of the revitalization process requires an analysis of the achievements and state of the company's operations. The financial situation, market, capacity utilization, production processes, employment and others are analyzed in order to reveal negative trends, bottlenecks and risks.

1. Introduction

In their operations, companies are exposed to various influences, which can cause problems. Problems must be solved, because if they are neglected, then several of them, although individually insignificant, together bring the company into difficulties or a certain state of crisis. It is important to understand that the dynamics of business, its exposure to various requirements, changes and adjustments inevitably lead to a smaller or larger crisis. Whether the company is stagnating or declining, conditions and trends must be observed in a timely manner and the necessary measures taken. This applies to all companies, whether manufacturing or service.

If business revenues decline, profits decrease or losses occur, liquidity issues arise, the company struggles to follow customers and market demands, capacity utilization drops, employment stagnates or declines, the social and legal situation deteriorates, and the company falls behind the competition – business revitalization must be undertaken. Companies have their own life cycle, including birth, growth, maturity, decline, and ultimately, termination.

We must act in the maturity phase, in order to prevent the mentioned negative trends. Therefore, the life of the company needs to be refreshed and renewed, returned

to the full meaning of life, and this is possible by carrying out the revitalization of its business processes and overall operations. In order to recognize and evaluate the situation as well as the movement in business, it is crucial to analyze the situation from the point of view of capacity utilization, production processes, markets, production programs, organization and human resources. Based on it, it is necessary to clearly define the causes of the condition [1, 5].

We have a variety of methods and standards at our disposal for the aforementioned activities in order to guide the process and ultimately define goals and strategies.

2. Analysis of business trends and achievements

The initial activity in the business revitalization process is conducting a business analysis, which includes an analysis of financial statements. These analyses are essential for identifying problems, existing risks, inconsistencies and deviations, outcomes and effects of processes, financial stability, or the company's ability to maintain and develop its operations. It is also important to analytically review the implementation of business policies, existing strategies, plans, goals, quality, sales, organizational functioning, and the information system, as well as to determine qualitative business indicators.

The central question of all analyses is – whether the company is in crisis and what problems it is facing in its operations. There may be several types of crises involved, such as economic, social, managerial, legal or regulatory crises, or even crises caused by force majeure.

2.1 Procurement and sales markets

Sources of supply, whether from foreign or domestic markets, are generally available in both quantity and quality. The key procurement problems or the most common problems are those that depend on the state of the company. Sources of supply, meeting the needs for materials and raw materials in sufficient quantities and specified qualities is crucial for the stability and success of the business. Irregular or inadequate supply of production and other processes is caused by:

- the company's lack of liquidity and, more broadly, its insolvency;
- significant changes in price growth, which can affect the competitiveness of sales and increase the share of procurement costs in total sales;
- a lack of working capital to finance raw materials and supplies, resulting in the inability to maintain customer relationships.

Such a situation in the company leads to the following consequences:

- inability to apply the supplier ranking list obtained through evaluation and selection, and the necessity to deviate from specifications/quality requirements for raw materials, supplies, and products;
- direct impact on the reduced utilization of production and other capacities, as well as a decline in the sales of the production and sales program;
- decline in product quality and the loss of business image and reputation.

These conditions, as identified through analysis, represent issues that the company must address in order to revive operations and intensify its business activities.

Like other business functions, sales play a very important and decisive role in the success of a company and its operations. Through sales trend analysis, we observe the achievement of sales plans, the loss or growth in the number of customers, the situation in specific markets, and the sustainability of the production and sales program.

The authors of this paper highlight an example of a sales analysis in a company where sales declined by 24% over a two-year period. The number of A and B category customers decreased by 18%, and they accounted for 80 to 85% of total sales. Exports dropped by more than 30%. Sales trend indicators show serious disruptions, with ongoing tendencies of negative developments. Such sales performance had an impact on:

- insufficient and irregular supply of raw materials, materials, semi-finished and finished products;
- irregular fulfillment of tender obligations and uncertainty in taking on new obligations, as well as incomplete assortments in the production and sales program, which consequently led to the realization of sales plans with high rates of decline;
- significant changes in the customer ranking list and increased levels of uncertainty, due to growing problems with accounts receivable;
- difficulties in concluding credit arrangements for the procurement of raw materials, and challenges in meeting existing credit obligations.

This snapshot of sales analysis highlights the need to undertake comprehensive changes [4, 5].

2.2 Capacity utilization

Capacity utilization is the most significant indicator of a company's activity—and indeed, of its overall success. The level of utilization reflects:

- how successful the procurement of raw materials is in terms of timeliness, quantities, quality, and pricing;
- the technical and technological capability of the production capacities, and accordingly, the employment of personnel, including their knowledge and skills;
- the availability of products for the market in relation to planned demand, as well as confirmation that the product quality has been validated by the market and end users.

The authors conducted a specific analysis of capacity utilization and, through a direct case study, determined that over a period of four (4) years, capacity utilization decreased by between 15% and 19% each year compared to the previous year. By the end of the period, the capacity utilization rate stood at 51%, which is 32% below the acceptable level.

This capacity utilization caused:

- mismatch between capacities in production lines and especially misalignment with energy capacities,
- reduction in performance/productivity per employee, and a direct impact on the growth of fixed costs and disruption in basic factors of production.

Revitalizing capacity utilization would achieve multiple positive results [1].

2.3 Process results

The company has established its processes according to the ISO 9001:2015 standard [6]. The main processes identified are the production processes and the sales process. Although the sales process has been addressed, the production processes have not achieved the planned results. Production plans were not met over a period of four (4) years. The annual decline in production ranged between 15% and 20% compared to the previous year. The supply of raw materials and supplies affected both capacity utilization and production levels, as the data has shown.

Support processes function adequately in relation to the main processes, such as procurement and others. However, their performance indicators are not aligned with the needs of the main processes. In the management processes, sufficient and concrete measures are not being taken. Such measures must be initiated because uncertainty continues, the need for changes is growing, these changes must be clearly defined, and they need to be managed effectively.

2.4 Structure of the production and sales program

The execution of plans is directly dependent on the realization of planned procurements. If procurements are not carried out according to the planned structure and volume, capacity utilization will be reduced, and consequently, production output will decline. In this situation, the production program will fall short of market needs both in terms of volume and structure. Specific analyses have shown a reduction in assortment and quantities by over 30%.

The sales program is diversified with products from external processes. A lack of funds for procurement has led to a shortage of these products, which make up the assortment of the overall sales program. The shortage of these products ranged from 25% to 30%. Analysis showed that the sales program's available volume was reduced by approximately 25%. As a result, sales decreased by 24%. Revitalizing business processes is inevitable, and the company must make concrete decisions in this situation.

2.5 Human resources

Human resources are a key asset for sustainable business operations and organizational development. Employee numbers, specifically their increase or decrease, are one of the criteria for diagnosing the state of the organization. Over a three-year period, employment in the observed organization decreased by 23%, indicating a crisis situation within the organization. Additionally, a decline in productivity and utilization of working hours by nearly 30% was recorded.

Besides obvious economic, financial, and managerial challenges, the company is clearly experiencing a social crisis, manifested in low wages and a high share of wages in the value of sales. The company must undertake, among other measures, the restructuring and reorganization of the organization.

2.6 Financial results

The financial performance analysis shows a critical situation and very poor trends. The achieved revenues cover the cost of materials, resources, and labor by just over 90%, indicating a critical misalignment of the basic factors of production. Business losses amount to 18% of revenues. Credit obligations consume 4% of the revenues generated. Fixed costs are rising due to a 7% decline in production and sales. Cash inflows and outflows are not aligned. Salary payments are delayed. All these indicators point to the urgent need for a well-designed business revitalization.

2.7 Development processes

In the past three years, the observed company has made no investments that would increase production, improve quality, or diversify the product assortment. The vision, mission, and strategy have not been updated. There have been no investments in product development, marketing activities, or adaptation processes, technical improvements, and other enhancements.

The quality management system and compliance with applicable regulations have been maintained only at basic levels and requirements. Development processes must no longer be delayed or halted. What is needed is the urgent recovery of the organization and the development of a healthy organization.

3. Status assessment

The previous section presents excerpts from the business analysis of key business functions. The assessment of this situation will be provided in the form of observations through the following questions: the market situation, the technical-technological and economic capacity capabilities, process functioning, social and legal conditions, the company's position relative to competitors, compliance with regulations, financial status, and qualification and diagnosis of the situation.

The following can be systematized as assessments of the situation:

- A lack of working capital and threatened liquidity cause irregular supply and a decline in production.
- A number of customers in both export and domestic markets have lost trust. Urgent investments must begin, primarily in ongoing operations, as the trend of declining business performance is expected to continue.
- The market has demand for, and wants, the company's products for end users because they meet quality requirements.
- A return to the market is possible, and there is potential for growth, but no further delay is acceptable. The condition of equipment and production

conditions must be improved. In their current state, they do not guarantee compliance with regulatory requirements or the achievement of efficiency and effectiveness. Processes must be redefined.
- Indebtedness and expenses exceeding revenues render the company incapable of making investments.
- The company is in a crisis state, and the management and governing bodies need to shift to reactive crisis management of a repulsive type to halt and suppress the acute crisis and mitigate it in order to ensure the company's survival.
- Obligations towards employees need to be resolved, otherwise the reduction in the number of employees will intensify.
- The competition has stable operations, is developing and growing both in market share and in technical-technological and economic terms.
- Regulations are constantly evolving, innovating, and becoming more complex, and changes must be followed and implemented in the processes.
- The financial situation reflects a crisis state, though it is an acutely manageable condition.

The assessments of the situation indicate the urgent need for action, specifically through a defined Business Revitalization project.

4. Causes and approaches for eliminating the causes

The causes of the described business situation are reflected in the following:

- Production supply is very difficult and, in certain situations, highly problematic due to insufficient working capital. This shortage has become a pathological problem. Debts and obligations are high and have persisted for a long period, while the volume of sales is not sufficient to enable a better business structure or cost distribution.
- There has been a loss of customers because orders are processed slowly and inadequately, and offers are issued hesitantly.
- A complete absence of improvements in resources, capacities, and facilities. The level of capacity utilization is low. Due to illiquidity, resolving regulatory and legal obligations is difficult.
- Open issues and problems have not been continuously addressed, which has halted growth, changes, and improvements, leading to a crisis situation.
- There has been a significant lag behind competitors. Greater inefficiencies exist in the processes.
- The disrupted and lost trust of customers and suppliers will persist. Illiquidity and insolvency will continue to affect operations in the upcoming period and will be difficult to resolve. Business will take place under conditions of global crisis, difficulties, and challenges.

- Significant changes will occur in attitudes towards costs, social issues, economic matters, regulatory requirements, and stringent demands from regulators. Competitors will continue to strengthen their positions.
- Fixed costs will continue to burden the business due to slower revenue growth.
- Changes in the political and legal environment must be anticipated.

Expected risks in the revitalization process and improvement of the situation:

- Defining the approach to sales growth, i.e., synchronizing activities related to procurement, production, quality, and other functions. Maintaining the sales structure with adjustments in technical, financial, and marketing measures.
- The time factor in business revitalization poses a particular risk, requiring decisive and swift action.
- Procurement management will be challenging, as it is necessary to secure funds and restore supplier trust.
- Resolving illiquidity and insolvency will be complex. Halting the reduction of employees, especially experienced and proven workers, must be established as a distinct process.
- The process of adapting to national and international regulations must continue, which also requires investment.
- Financial liabilities and interest burdens need to be addressed. Resolving legal disputes that may weigh on the business must also be managed.

Available resources, as support for revitalization, must be identified. Among others, these include: production, energy, technical, IT, spatial and other resources; personnel – both existing and additional potential; market potential; business resources from experience and skills; spatial resources that ensure growth and further development; financial resources, considering all sources as potential.

Revitalization as a process involves, besides analyses and assessments, the development of plans and programs, as well as various projects. It is crucial to plan accordingly, use well-known methods and techniques for improvements, as well as management methods and principles. Available management models are also well known. Commonly used methods include, for example, Pareto analysis, SWOT analysis, case studies, along with the mandatory use of the PDCA cycle. Quality management system standards are also of great help and benefit [5, 7, 8].

5. Goals of revitalization

Revitalization is understood as a process involving a series of coordinated activities aimed at revitalizing and stabilizing business operations to ensure survival. In this context, the following goals can be set:

- Establish procurement in the necessary volume and structure to enable full utilization of capacities and generate sales revenue sufficient to cover business and other expenses.

- Restore the company's market presence with a product range that meets customer requirements.
- Free the company from legal and social issues and uncertainties. Establish cost control and cash flow management to ensure positive results and financial security.
- Monitor international and national regulations and adapt business operations accordingly.
- Establish development processes for products, production lines, human and other resources to secure long-term success and survival.

6. Activities in business revitalization

6.1 Stabilization Strategy

It is crucial to stop the negative trends, stabilize, and revive business operations. The stabilization strategy will be implemented through the following revitalization issues.

6.1.1 Financial Revitalization (Securing working capital, resolving legal and social issues, addressing problems with other obligations)

6.1.2 Sales Revitalization (Ensuring sufficient quantities of products from internal processes, ensuring sufficient quantities of products from external processes, structural alignment of sales – assortment, markets, customers)

6.1.3 Organizational Revitalization (Reviewing process structure, authorizations and responsibilities, structuring and shaping the organization – technical and organizational improvements, increasing productivity and capacity utilization)

6.1.4 Revitalization of Production Capacities (Removal of bottlenecks, increasing efficiency and effectiveness, establishing economically justified operating modes)

6.1.5 Revitalization of Production and Sales Program (Determining the production program from technological and economic perspectives, determining the program from external processes from an economic standpoint)

6.2 Internal Growth Strategy

Growth must be planned, monitored, achieved, analyzed, and necessary corrective measures must be taken. Anything contrary to this will lead the company to decline, as its economic, financial, and technical performance will deteriorate. For growth, necessary skills, experience, determination, and capital are required.

If we talk about physical growth, it means growth in production and sales. Financial growth implies an increase in revenues, profitability, ability to meet obligations, and maintenance of stability. Growth also includes increases in prices, quantities, market share, exports, growth through new customers, and so on.

Some activities that enable internal growth may include: preparing products for the market (packaging, design, requirements, regulations, informational materials, etc.), technical improvements to increase equipment utilization and quality, business

diversification (increasing volume and desired changes in structure), increasing capacity utilization and expanding the product offer, market expansion, technical and technological improvements (increasing profitability, productivity, efficiency), and aligning business operations with regulations.

6.3 External Growth Strategy

External growth comes into focus once business stabilization and internal growth are achieved. The key issues that need to be strategically defined include: the structure, use, and management of spatial, technical, and human resources; the concept of a new structure for modernization and business model; and defining the development of existing activities and new projects. The implementation of this strategy involves diverse knowledge, skills, the application of methods and techniques, a project-based approach, and teamwork.

7. Measures and control of project implementation

The content of the project, the complexity of the issues, and the scope of tasks, as well as the inevitability of changing the situation, require a series of activities. An operational plan and program for project implementation should be prepared with clear tasks, methods of execution, objectives, costs, project leaders, implementation methods, and ways of reporting and verification (PDCA approach).

All set goals must be measurable. Project progress flows should be analyzed quarterly, achieved goals and effects evaluated, and any necessary corrections identified for further activities to achieve the objectives.

A special plan and program should be developed related to the financial situation remediation, with analysis and projected solutions. It is crucial to work on ensuring product availability for the market continuously and to initiate sales activities with a dedicated marketing plan, considering the longer absence from the market.

All these activities, at each control point, must be documented, reviewed, evaluated, and monitored with necessary decisions, reports, and similar documentation.

8. Expected effects

A successfully managed and implemented project will undoubtedly yield results. Among others, the following effects are expected: the trend of further decline and disappearance from the market will be halted, customer confidence in both domestic and international markets will be restored, export growth will be ensured, quality will improve and resources will be optimized, and financial burdens will be overcome.

9. Conclusion

Changes are difficult to predict, especially from the perspective of external influences. Many internal influences are regularly analyzed, yet organizations often struggle to identify them as disruptions—most of which significantly alter the organization's condition. Therefore, it is important and crucial to regularly analyze the current state, evaluate it, and forecast its development. Timely action is necessary, as is making and implementing appropriate decisions.

The company is constantly undergoing movement, business dynamics, and changes—it is a flexible organism, which is why internal control and action are essential. In such circumstances, companies fall into crisis, and they must assess it and determine how and by what means to overcome it. The essence is that the business is in a state with negative trends, and its vitality and level of capability are declining. Typically, companies in such situations must enter a phase of revival or recovery. This means that revitalization processes must be thoughtfully designed and undertaken.

The implementation of the revitalization project requires a responsible approach and effort, and ultimately, the mobilization of all available resources.

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Continuous improvements of the quality management system

Muamer Peljto, Mersiha Olovčić and Adis Čevra

[1] TUV THURINGEN ADRIA d.o.o. Sarajevo, Bosnia and Herzegovina

E-mail: muamer.peljto@tuvadria.ba

Abstract. Creativity represents the victory of originality over habits. This means working in processes differently and abandoning the routine. Continuous improvements in an organization are based on constant improvement of processes, products and services in order to increase efficiency, reduce costs and improve customer satisfaction. The aim of this paper is to point out possible improvements in order to achieve continuous improvement and the path to excellence. Continuous improvement is one of the most critical aspects of total quality management. To achieve long-term success using a continuous improvement process, an organization needs everyone involved to pull together and be willing to continually make small improvements in their work context. For that to happen, it is important that the framework conditions are right. Top management must make a conscious decision in favor of a continuous system improvement process and consolidate it into the corporate culture. This can be done through further training measures, integrating the PDCA cycle into processes, workflows, and working hours. If you don't track your progress every day, you're not practicing continuous improvement. Lean thinking is about the intentional and targeted practices of applying the scientific method to create progress every day. This philosophy is based on the concept of "respect for people." Utilizing human potential, teamwork, and everyday habits are the key to continuous improvement.

1. Introduction

The modern market demands that organizations continuously improve their business processes in order to meet increasingly strict quality standards and customer expectations. A Quality Management System (QMS) is not a static framework, but a dynamic process that requires constant review, evaluation, and adaptation to effectively respond to changes in the environment.

Continuous improvement is a strategic approach aimed at achieving long-term excellence through systematic activities focused on process enhancement, variation reduction, and waste elimination. This paper will explore in detail the methodologies that support the establishment of a quality-oriented culture and provide guidelines for implementing such approaches within organizations. This approach is becoming

imperative, particularly in the context of global competition and increasingly demanding end users.

In today's business environment, organizations are faced with increasing demands for competitiveness, efficiency, and compliance with ISO standards. One of the key success factors is the continuous improvement of the quality management system. Continuous improvement is not only a recommended practice but also a core requirement of standards such as ISO 9001, which encourages organizations to systematically identify and implement changes that lead to greater customer satisfaction and more efficient operations. This paper aims to highlight the importance, methods, and challenges of competitive improvement of quality management systems through the analysis of standard approaches and examples of good practice.

2. Theoretical Framework and Methodology of Continuous Improvement

The quality management system in the field of manufacturing and assembly of metal structures encompasses a set of policies, procedures, and processes that ensure products meet customer requirements and standards such as ISO 9001 and EN 1090.

Continuous improvement represents an ongoing process of enhancement that involves the entire organization, from management to operational sectors. The foundation of this approach lies in the belief that small but consistent changes over time can lead to significant improvements in overall efficiency and the quality of products and services. This principle originates from Japanese business philosophy, where a focus on continuous development became a key driver of success. It was later transformed into formal methodologies now used by numerous organizations worldwide.

Organizations have access to several methodologies for systematic process improvement. Among the most commonly applied are:

- The Plan-Do-Check-Act (PDCA) methodology can be a useful tool to define, implement and control corrective actions and improvements. The PDCA is a dynamic methodology that can be deployed within each of the organization's processes and across their interactions. It is intimately associated with planning, implementation, verification and improvement [7].
- Kaizen Philosophy: Kaizen is a concept that promotes the idea that every improvement, no matter how small, contributes to overall progress. This methodology requires the constant involvement of all employees and encourages small but continuous changes. Through Kaizen, organizations foster a culture in which every mistake is seen as an opportunity for learning and improvement.
- Six Sigma: The Six Sigma methodology uses statistical tools to identify and eliminate the causes of defects. The DMAIC model (Define, Measure, Analyze, Improve, Control) provides a structured approach to problem-solving, enabling measurable improvements by reducing variation and increasing process reliability.

- Lean Management: The Lean approach emphasizes the elimination of waste and the optimization of value stream flow. The focus is on maximizing activities that add value to the end customers while minimizing those that represent resource waste. This approach is often applied in combination with Six Sigma to achieve high efficiency.

Figure 1. PDCA methodology [6].

Metal structures require a high level of precision, reliability, and safety, especially in construction where errors can lead to serious consequences. In this context, a Quality Management System (QMS) involves raw material control, process control, weld inspection, joint inspection, testing of finished structures, and documentation of every step in the process.

3. Principles and Tools of Continuous Improvement

Continuous improvement is an ongoing process of seeking opportunities to enhance processes, products, and services. In the metal structures industry, in addition to the previously mentioned elements, it necessarily includes internal audits and corrective actions, control charts and Statistical Process Control (SPC), the Ishikawa diagram (cause-and-effect diagram), the 5S methodology for workplace organization and efficiency, as well as the FMEA method (Failure Mode and Effects Analysis) for identifying causes and consequences.

Effective use of these tools enables the identification of bottlenecks in production, reduces the number of welding and assembly errors, and improves the overall reliability of structures. The first step in implementing continuous improvement consists of a detailed analysis of existing processes. This includes:

- Assessment of current standards: Mapping all key processes and identifying the current quality level.
- Identification of weak points: Conducting internal and external audits to determine potential problems and risks.

- Data collection: Using quantitative and qualitative methods to identify the main causes of irregularities.

3.1 Planning and Goal Setting

After the initial analysis, the process moves into the planning phase. Here, it is crucial to define SMART goals (Specific, Measurable, Achievable, Relevant, Time-bound) that will serve as the basis for measuring success:

- Strategic goals: Setting long-term objectives for quality improvement.
- Operational goals: Defining short-term, measurable activities that contribute to achieving the strategic goals.
- Key Performance Indicators (KPIs): Establishing key success indicators that will be regularly monitored and evaluated.

3.2 Implementation and Training

After the goals have been defined, practical implementation begins:

- Employee training: Systematic instruction on new procedures and methods, including internal communication and workshops.
- Introducing changes into operational processes: Gradual implementation of improved procedures, with close monitoring of the impact and readiness to respond to challenges.
- Support through digitalization: Modern IT platforms enable real-time data monitoring and analysis, fostering transparency and rapid response to potential shortcomings.

3.3 Control and Evaluation of Results

Continuous monitoring and evaluation ensure the long-term success of the system:

- Regular audits: Internal and external system assessments enable timely detection of deviations from planned objectives.
- Feedback mechanisms: Input from employees and customers provides insights into practical issues, allowing for prompt corrective actions.
- Iterative approach: Based on evaluation results, the improvement process is reviewed and adjusted, ensuring a continuous cycle of improvement.

4. Analysis, Discussion, and Challenges

Continuous improvement represents a systematic approach to enhancing business processes, products, and services with the goal of achieving greater efficiency, quality, and customer satisfaction. This philosophy, often associated with concepts such as Kaizen, Lean Management, or Total Quality Management (TQM), is based on the idea that small, continuous changes accumulate over time into significant results.

4.1 Benefits of Continuous Improvement

The application of continuous improvement brings numerous benefits to organizations:

1. Increase in Efficiency and Productivity

By identifying and eliminating unnecessary activities, bottlenecks, and waste, organizations can optimize their workflows. This results in:

- Faster task completion
- Reduced downtime and interruptions
- Better utilization of resources

2. Improvement of Product and Service Quality

Continuous analysis and quality improvement enable the organization to:

- Reduce errors and complaints
- Respond to changing customer needs
- Maintain high standards and compliance with regulations

3. Greater Customer Satisfaction

Process and quality improvements result in a better customer experience, which leads to:

- Increased customer loyalty
- Positive market reputation
- Easier acquisition of new clients

4. Employee Engagement and Development of Team Culture

Continuous improvements often involve all levels of employees. This contributes to:

- A greater sense of responsibility and belonging
- Knowledge sharing and teamwork
- Motivation and the development of innovative thinking

5. Reduction of Operating Costs

Through process improvements, operating costs are reduced because:

- The amount of waste and inefficient activities is reduced
- Energy, material, and labor costs are optimized
- The need for repairs and subsequent corrections is minimized

6. Faster Adaptation to Market Changes

Organizations that continuously improve their operations adapt more easily to changes in the environment, competition, or customer requirements. This results in:

- Increased agility and resilience to crises
- Easier adoption of new technologies and methods
- Improved strategic decision-making

Improvements are the result of applying experience, professionalism, and dedication within the framework of existing knowledge [5]. Continuous improvement requires strong management support and active employee involvement:

- Management must provide the strategic framework, resources, and training, as well as motivate employees to participate in improvement processes. Integrating QMS objectives into strategic planning is key to success.

- Employees, especially those directly involved in production and assembly, have firsthand insight into daily problems. Their involvement through workshops, suggestions, and evaluation of existing procedures contributes to real and sustainable improvement.

To ensure the effectiveness of continuous improvements, regular monitoring and measurement of results are essential. In the metal construction industry, this is most often carried out through:

- Key Performance Indicators (KPIs) such as the number of complaints, average production time, and material utilization rate,
- Internal and external system audits, regular factory inspections,
- Monitoring customer satisfaction through surveys and feedback,
- Analysis of deviations and implementation of corrective and preventive actions.

The results of these measurements serve as a basis for decision-making regarding further improvements and investments.

4.2 Challenges in Implementation

Despite significant advantages, the implementation of continuous improvements may face obstacles:

- Adaptation to change: Older organizational structures and conservative employee attitudes sometimes hinder the acceptance of new methods, requiring additional efforts in motivation and training.
- Resource demands: Implementing new systems requires investments in technology, training, and organizational restructuring, which can be a significant challenge, especially for smaller companies.
- Accurate measurement of results: Without establishing appropriate KPIs and performance monitoring, evaluating effectiveness can be inadequate, making timely process correction difficult.
- Cultural barriers: Changing the organizational culture to embrace the concept of continuous improvement requires time, patience, and ongoing effort from management.

4.3 Discussion: Practical Examples and Experiences

Practical examples show that companies that take continuous improvement seriously achieve significant results. For instance, manufacturing sector companies successfully apply the PDCA cycle to identify and eliminate disruptions in production lines, resulting in a significant reduction of defects. On the other hand, organizations that adopt the Kaizen philosophy often report increased employee engagement and innovation, as open communication and the proposal of improvements at all levels are encouraged.

Digital tools, such as process management software, enable real-time monitoring of results and faster decision-making. The challenge remains in adapting global

standards to the specifics of individual markets, but the application of flexible methodologies allows for successful resolution of these issues.

A domestic company specializing in the production of steel halls faced an increased number of nonconformities in welding. Analysis revealed that the problem was due to inconsistent weld quality and a lack of standardized procedures. By applying the PDCA cycle, an improvement team was formed, checklists were introduced, and welder training was enhanced. The result was a 40% reduction in complaints over a six-month period and a 10% increase in productivity. In this case, welders and the production manager implemented two improvement methods: FMEA and the 8D method.

5. Conclusion

Continuous improvements in quality management systems represent an essential part of modern business due to their ability to enhance processes, reduce costs, and increase customer satisfaction. Throughout this paper, the fundamental concepts and methodologies—PDCA, Kaizen, Six Sigma, and Lean—have been highlighted, which every organization can adapt to its specific needs.

This forms the basis for the long-term competitiveness and stability of the organization. In the field of metal constructions, where quality requirements are particularly high, such approaches bring mutual benefits in the form of reduced errors, increased customer satisfaction, and process optimization. Success depends on the strategic approach of management, active employee involvement, and the application of appropriate tools and methods.

In today's market, organizations that continuously improve their QMS can survive and thrive in their environment. Continuous improvement is no longer a choice — it is a necessity for organizations that want to be market leaders.

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Integrated management system

Muamer Peljto, Aleksandra Obradović and Dragan Simović

TUV THURINGEN ADRIA d.o.o. Sarajevo, Bosnia and Herzegovina

E-mail: muamer.peljto@tuvadria.ba

Abstract. An integrated management system (IMS) represents the unification of multiple standardized systems that enables an organization to operate more efficiently and in a more coordinated manner. This approach facilitates resource management, reduces costs, and increases competitiveness. The IMS framework provides a model for incorporating common elements of an integrated management system in approach and implementation. Deming's PDCA cycle (Plan-Do-Check-Act) plays a key role in an integrated management system that combines multiple standards. This cycle is important for IMS because it enables continuous improvement of all integrated processes. It helps in aligning with the various ISO standards that the organization has introduced and implemented through a common management framework. It ensures consistency and efficiency across these areas of the IMS. By implementing this framework in all organizations, it should be useful as a checklist and guideline to ensure the coverage of all processes in the organization. The prerequisite for the functioning of IMS in an organization is continuous education, lifelong learning, and teamwork. The goal is to avoid multiple efforts in internal and external audits. The synergy created by the integrated system also sharpens the focus on opportunities and risks within the organization. The main advantages are greater efficiency and transparency in the organization.

1. Introduction

The Integrated Management System (IMS) combines multiple management standards into a unified framework, resulting in improved efficiency, legal compliance, and increased productivity. This approach eliminates process duplication, reduces costs, and enhances communication within the organization.

In today's business environment, organizations increasingly face the need to effectively manage various aspects of operations, including product and service quality, environmental protection, employee health and safety, and social responsibility. Traditionally, these systems were developed separately, leading to overlap and inefficiencies. The Integrated Management System (IMS) addresses these challenges by integrating standards into one coherent system

The development of the Integrated Management System (IMS) is linked to the need for organizations to adapt to increasingly complex regulations and the growing demand for sustainable business practices. By integrating multiple management systems,

organizations can improve the quality of their products and services, reduce their environmental footprint, and ensure a safe and healthy working environment.

The Integrated Management System enables an organization to manage the requirements of standards such as ISO 9001 (quality), ISO 14001 (environmental protection), and ISO 45001 (occupational health and safety) in a structured and synergistic manner. The integration of these standards contributes to better process alignment, reduced administrative burden, greater stakeholder satisfaction, and the continuous improvement of overall business performance.

This paper aims to present the principles of the Integrated Management System (IMS), its benefits and challenges, as well as practical examples of its implementation.

2. Components of the Integrated Management System (IMS)

The Integrated Management System (IMS) provides a framework for managing multiple aspects of an organization through a unified policy, objectives, documentation, and audit system. IMS encompasses various standards that are integrated into a single management system. Common standards included in an IMS are:

- ISO 9001 – Quality Management System. This standard ensures the continuous improvement of product and service quality through systematic process management and a focus on customer satisfaction.
- ISO 14001 – Environmental Management System. It aims to minimize the negative environmental impact of the organization through responsible resource management and effective environmental strategies.
- ISO 45001 – Occupational Health and Safety Management System. This standard enables organizations to identify and manage health and safety risks to employees, thereby improving the working environment.

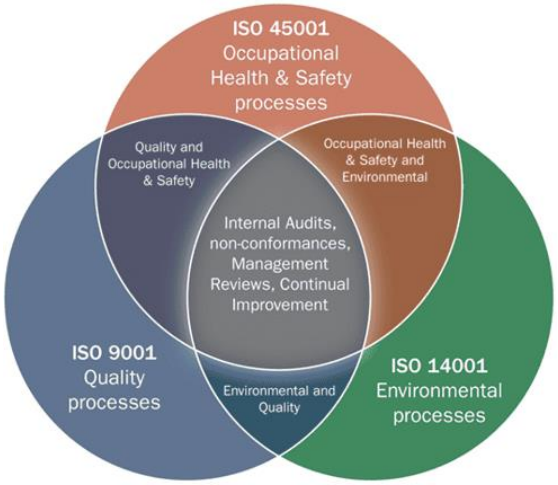

Figure 1. Integrated management system.

Figure 1 illustrates the conceptual model of an Integrated Management System (IMS) that consolidates the requirements of various ISO standards (ISO 9001, ISO 14001, ISO 45001) into a coherent framework. The model highlights common components such as policy, objectives, documentation, and audits, which are used to manage quality, environmental protection, and occupational health and safety. This type of visualization helps in understanding how different systems are integrated into a unified structure.

In addition to these standards, an IMS may also include other systems, such as ISO 27001 (information security management) or ISO 50001 (energy management), depending on the specific needs of the organization.

3. Advantages and Challenges

The IMS is designed to improve an organization's operations: it must be effective, efficient, and deliver better results for all stakeholders involved. If it fails to do so, it misses its purpose and will likely become merely a bureaucratic burden [1]. Advantages of IMS:

- Greater involvement and commitment from management, which is significantly higher when all objectives, resources, and measures are integrated and jointly reviewed.
- Establishment of a unified policy for documents and records, resulting in savings from a reduced number of policies.
- Unified IMS training that saves time and money, and reduces employee confusion caused by separate training for multiple systems.
- Increased customer trust and a better market and social image.
- More effective internal audits and preparation for IMS certification compared to individual audits for each standard.
- Cheaper and simpler certification compared to certifying separate management systems [2,3].

Challenges of IMS: The need for initial resources, employee engagement, and balancing technical and human factors.

4. The IMS Implementation Process

The development of quality management experienced significant expansion at the end of the second and the beginning of the third millennium. Previously, quality control of products was performed by quality inspectors, whereas today, total quality management and the application of various methods and tools are required. Managers struggling with the dramatic increase in complexity of market, technical, organizational, and social issues often find it difficult to grasp modern trends in management system development. Standardization of management systems has become a paramount issue for organizational business operations in the global market of the 21st century. Certification of various standardized management systems is essential. Integration of

all these systems with existing systems in an organization results in a single operational management system, which is a top priority for managers [3]. Today, Industry 4.0 represents a revolutionary breakthrough in how the manufacturing and service sectors operate. Some of the benefits Industry 4.0 brings to enterprises include increased productivity, more flexible production enabled by smart machines and robots, improved product quality, and enhanced communication between employees, suppliers, and partners. Industry 4.0 introduces new modes of communication between technology and people [4].

The implementation of an Integrated Management System (IMS) that includes ISO 9001 (quality), ISO 14001 (environmental protection), and ISO 45001 (occupational health and safety) requires a structured approach through several key steps. The implementation process typically involves the following main stages:

1. Initial analysis (gap analysis) – Assess the current state of the organization in relation to the requirements of ISO 9001, 14001, and 45001. Identify existing policies, procedures, and practices that can already be utilized.
2. Defining the scope of the IMS application – Define the scope of the management system (which locations, processes, products/services). Align it with the company's strategic objectives.
3. Appoint a management representative for IMS and establish a quality team.
4. Training and awareness raising – Educate the quality team and key employees about the standard requirements. Conduct workshops to understand the purpose and benefits of the IMS.
5. Development of IMS documentation. Create the necessary procedures and instructions for key processes (e.g., risk management, document control, incident response, etc.). Harmonize system documentation (a unified documentation for all three standards).
6. Risk identification and legal compliance. Identify risks and opportunities (qualitative and quantitative analysis). Identify legal and other obligations related to quality, environment, and occupational health and safety.
7. System implementation. Execute the developed procedures in daily operations. Ensure that all employees apply the IMS in practice. Integrate the requirements throughout existing business processes.
8. Monitoring and measurement. Establish performance indicators (KPIs) for quality, environment, and occupational health and safety. Monitor goal achievement and regularly analyze reports during meetings.
9. Internal audit. Organize internal audits in accordance with ISO 19011 requirements. Identify non-conformities and opportunities for improvement. Train internal auditors or engage an external auditor.
10. Management review. Hold management review meetings to evaluate the effectiveness of the IMS. Make decisions regarding improvements.

11. Corrective actions. Respond to identified non-conformities. Implement corrective actions for continuous improvement.
12. Certification. Select an accredited certification body. The certification audit is conducted in two stages:
    - Stage 1: Document review
    - Stage 2: Verification of system implementation in practice.
13. Maintenance and continuous improvement of the IMS. Regularly monitor changes in legal requirements. Conduct internal audits, management reviews, and corrective actions. Involve employees and develop a culture of quality, safety, and environmental responsibility.

4.1. Case Study

The application of IMS in the production of cabins for construction machinery demonstrates how the integration of standards improves quality, safety, and environmental protection. The process of manufacturing cabins requires a high level of precision, safety, and compliance with technical and legal requirements. The implementation of IMS enables a systematic approach to managing quality, environmental protection, and occupational health and safety throughout all stages of production. In cabin manufacturing, product quality directly impacts the functionality, durability, and safety of the end user. The IMS allows for:

- Standardization of production processes (cutting, welding, assembly, and painting)
- Monitoring dimensional accuracy and mechanical properties
- Supplier control of materials (steel)
- Internal quality control and corrective actions.

The production process includes management of chemicals and waste (ISO 14001), welding, and energy consumption. The IMS requires:

- Identification and control of environmental aspects (emissions to air, water, and soil)
- Implementation of measures for the rational use of energy and materials
- Proper storage and disposal of waste. This is especially important for the application and implementation of the ISO 14001 standard.

Regarding the implementation of ISO 45001 in the cabin manufacturing process, there are risks of injuries due to heavy welding and grinding activities. The application of IMS enables:

- Risk assessment for specific workstations (welder, assembler, painter)
- Mandatory use of personal protective equipment (PPE)
- Mandatory machine maintenance and employee training

Procedures for handling accidents and emergencies (conducting emergency drills, for example, oil spills in production).

The introduction of IMS requires well-developed two-way communication. In organizations with a one-way communication model, management must work on building a culture of mutual trust.

5. Recommendations for Organizations

To establish an integrated management system, the following is recommended:

- Digitalization of the IMS – the introduction of software tools for managing documentation, audits, and risk analysis can further increase system efficiency and facilitate its application in daily operations.
- Continuous employee training – regular education on IMS principles, occupational safety, and environmental protection is essential for maintaining awareness and responsibility in daily tasks.
- Employee involvement in improvement processes – encouraging employees to report non-conformities, suggest improvements, and participate in internal audits strengthens the organizational culture of quality and safety.
- Regular evaluation of IMS performance – through internal audits, process analyses, and management reviews, it is essential to regularly assess the effectiveness of the IMS and adapt it to changes in the environment.
- Monitoring trends and innovations in the IMS field – adapting the IMS to modern market demands, such as standards for energy efficiency (ISO 50001) or social responsibility (ISO 26000), can further enhance the organization's image and sustainability.

To introduce, implement, and maintain an Integrated Management System (IMS), a high level of communication within the organization is essential. In current practice, communication in many of our organizations is underdeveloped—most often one-way, top-down, and lacking feedback. Feedback is rarely passed upward, or it is irregular and incomplete because no one seems to care. Arrogant management tends to believe it knows everything and often dismisses well-intentioned suggestions, especially when they do not align with its objectives. As a result, feedback is usually limited to isolated incidents, low wages, and poor working conditions.

Modern organizational management faces numerous requirements that it must fulfill. In addition to various legal obligations related to finance, human resources, and the quality of processes and products, there are also standardized requirements concerning the management system itself. Leadership within a quality management system includes the obligation to build an Integrated Management System [3].

The role of organizational management is reflected in the following:

- Defines the organization's quality policy and objectives;
- Ensures a customer-focused approach throughout the organization;
- Ensures that appropriate processes are implemented to meet customer requirements and achieve set objectives;
- Provides the necessary resources;

- Compares achieved results with established objectives;
- Makes decisions related to quality policy and objectives; and
- Makes decisions regarding improvement activities.

Through its leadership and professional approach, top management demonstrates its commitment to the above-mentioned responsibilities and creates an environment in which awareness of the need to meet the requirements of all interested parties prevails. In this context, continuous review of the quality policy and strategic objectives is necessary [5].

6. Conclusion

The Integrated Management System (IMS) offers organizations the opportunity to optimize operations by unifying key management processes. Although the implementation of an IMS can be challenging, its long-term benefits include improved efficiency, regulatory compliance, and increased competitiveness. Given the growing demand for sustainable and responsible business practices, IMS is becoming an essential tool for modern organizations. The introduction of IMS in the production process of machine cabins demonstrates tangible benefits: reduced errors, efficient resource management, and increased employee safety. IMS is becoming indispensable for any organization striving for continuous improvement and long-term sustainability in the market.

Through the integration of multiple standard requirements, an organization gains a unified framework that enables effective management of production processes, reduces negative environmental impacts, and contributes to the protection of employee health and safety. In a production environment, where technically demanding and potentially hazardous processes occur simultaneously, an IMS supports clearer allocation of responsibilities, improved interdepartmental communication, and the establishment of continuous improvement as a core operational principle. Through standardized procedures, the organization efficiently manages resources, minimizes errors, and ensures greater compliance with legal regulations.

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The Future of Preschool Education in BiH: A Critical Review of Accreditation Standards in the Education Sector

Enes Dedić

University of Bihac, Bosnia and Herzegovina

E-mail: enes.dedic@unbi.ba

Abstract. Education in Bosnia and Herzegovina has several levels. Quality assurance standards are fundamental to the development of a strong education system in Bosnia and Herzegovina (BiH). This paper critically examines the accreditation frameworks governing preschool education, with a focus on the standards (Quality Standards for Preschool Institutions) set by the Agency for Pre-Primary, Primary, and Secondary Education (APOSO) and the standards set by the Agency for Development of Higher Education and Quality Assurance (HEA). It evaluates the alignment of these frameworks with international best practices and their effectiveness in ensuring high-quality early childhood education. The study highlights key challenges, including inconsistencies in accreditation procedures, regional disparities in implementation, and gaps in monitoring mechanisms. It also analyses differences in approach between these two sets of standards, since both of them "came" from abroad. Additionally, the paper discusses the future of preschool education in BiH in the context of existing (higher education) study programs and challenges thereof. The findings aim to support policy development and contribute to a more cohesive and internationally competitive preschool education system in BiH.

1. Education in Bosnia and Herzegovina

Education in Bosnia and Herzegovina is organized in a traditional way, across several levels, starting with preschool education, through elementary, secondary and higher education, as a part of regular, formal educational structures. Apart from these, there are other specific providers of education as such, both as part of formal, but also informal or non-formal education institutions. The status of any education level in Bosnia and Herzegovina is not unique, but rather compartmentalized through ten cantonal ministries, meaning ten systems, plus another one in RS Entity and Brčko District, and all these are encompassed by the national system. However, all these systems have minimal variations, meaning that they share the key elements. Therefore, when we discuss the system as such, it should be kept in mind that there might be minor differences. Since the scope of this paper is not to go into detail in this matter, it should suffice to say that one description will fit the purpose of this paper, and the differences

will also serve as a reflection point later on. The education levels in BiH are classified according to ISCED 2011 where ISCED 0 corresponds to preschool education, and ISCED 8 to doctoral (PhD) qualification. [1]

The post-war atmosphere adds to this virtual diversity too, requiring all the local laws on pre-school education to be harmonized to the Framework Law on Pre-school Education in BiH. Furthermore, pre-school education is organized in both private and public institutions, providing some diversity in approach, resources available, as well as practices and languages used. In 2016/2017 school year, there were only 10% of overall children population attending preschool education institutions in FBiH, and coupled with non-mandatory education in RS, "BiH is far from the European average when it comes to the inclusion of children under the age of six in preschool education." [2] The European target for 2030 is ≥96% of children between 3 years of age and primary school to have participated in early childhood education and care. [3] Other reports provide varying data, e.g. a UNICEF report claims that "In Bosnia and Herzegovina, only 44% of children aged 3 to 6 go to kindergarten." [4]

Numerous analyses were performed, pointing out specific and focused issues about the education sector in BiH. A USAID report stressed that "evidence-based data about the quality of basic education in BiH has been limited" [5] and more than 40% of BiH citizens are not satisfied with preschool education. The major obstacles reported [5] were that learning outcomes are not used, and programs are implemented differently. These were superseded by the Common Core of the Integral Developmental Programs for Preschool Education Defined on Learning Outcomes (CCIDP) by the Agency for Preschool, Primary, and Secondary Education (APOSO). [6]

Apart from the Agency for Preschool, Primary, and Secondary Education (APOSO) and local educational authorities, as a part of professional and independent authority, there are pedagogical institutes too, the Agency for Development of Higher Education and Quality Assurance (HEA) and the Center for Information and Recognition of Qualifications in Higher Education (CIP). Their roles are to instruct and monitor educational practices and quality. Another, less formal, but still official bodies exist, including the Rectors' Conference of Bosnia and Herzegovina, the Conference of Ministers of Education in BiH and the Council for General Education in BiH. Preschool education is provided as: nursery (children aged 6 months to 3 years), kindergarten (children aged 3 to 6 years), and preschool preparation (prior to starting elementary school). Since it is not compulsory, there are no guaranteed places for all the children, it poses a serious challenge to both larger cities and very small local communities. Only preschool preparation is mandatory but differs in duration and quantity across BiH.

Primary education is compulsory and is attended by children aged 6-15. It lasts nine years and is delivered in Bosnian, Croatian or Serbian language. There are some international schools who provide elementary education in foreign languages too. Several individual policies across Bosnia and Herzegovina reflect efforts to enhance educational quality. Nevertheless, it is the system evaluations and the lack of

co-operation at the state level that does not allow setting meaningful goals. As an illustration, "there are no current strategic documents or platforms at the BiH-level related to primary and secondary schooling." [7] However, education in BiH is very similar to education in neighboring countries and as such is depicted in various reports as the region that is struggling to attain the same level of development as many of its neighbors [8] and is designated as an integral part of the Western Balkans region.

2. Quality assurance standards in education

A global consensus exists that education must be quality assured, and it has to be done through systemic transformation, robust policies, and sustained investment. UNESCO Global Education Monitoring Report from 2004 reemphasizes that "Quality is at the heart of education. It influences what students learn, how well they learn and what benefits they draw from their education." [9] The idea that "quality is at the heart of education" [10] was formulated in the World Education Forum in 2000 and adopted by 164 governments that committed themselves to implementing EFA. Nevertheless, Antonio Guterres in 2022 proclaimed that "education is in a deep crisis" [11] and called for enhanced quality in all aspects of education.

United Nations under the umbrella of Sustainable Development Goals 2030 defined "inclusive and equitable quality education" [12] as one of the key development goals for all. It sparked numerous initiatives, translations and implementation, across the globe, illustrating the importance and significance of quality education as such. Peter Thompson, reiterated the significance of quality education again in 2017 emphasizing that "Inclusive, equitable and quality education goes to the heart of the 2030 Agenda as a key enabler of sustainable development." [13]

The topic of quality in preschool education as a topic could be traced in numerous European agendas and policies. Camović and Bećirović-Karabegović convey the European stance on the matter of quality and implementing SDG 4. [14] Discussions about educational quality are no longer simply abstract ideals; they are increasingly linked to measurable indicators and system-level responsibilities. Quality assurance (QA) has emerged as a core component of modern education governance, ensuring that institutions are not only meeting basic requirements but are also striving for continuous improvement. Nowhere is this more critical than in preschool education, where the absence of clear standards and monitoring can significantly impact long-term outcomes for children.

UNICEF policy document [15] contains all the major issues relevant for establishing a comprehensive quality system. *A Framework in Support of Universal Quality Pre-Primary Education* "outlines the key building blocks of an effective pre-primary system to ensure children's optimal learning and development in early childhood education programmes." [16] Furthermore, it poses that standards in preschool education should serve as a foundational framework for ensuring consistency, equity, and quality across early childhood programs and providers, in all

the contexts and areas. They should define the expectations for what children should experience and achieve in their early years, covering key areas such as curriculum content, staff qualifications, learning environments, child development outcomes, and health and safety. Well-designed standards help align practice with child's developmental goals, guide educator training, and inform monitoring and evaluation processes. By setting clear benchmarks, standards not only support children's holistic development but also provide a basis for accountability and quality improvement at the institutional and system level.

2.1 Accreditation frameworks governing preschool education

When it comes to quality issues, the sole definition of quality, and subsequently, accreditation as such, requires some common grounds. Camović and Bećirović-Karabegović promote the number of elements that define the quality. [14] No matter which definition is adopted, the quality as such must be analyzed and verified by an independent authority. The process is known as accreditation and in BiH there are Quality Standards for Preschool Institutions Services. [17] It is a broad quality framework that includes six thematic areas of quality: Environment, Curriculum, Staff, Building partnerships with families and the local community, Management, leadership and funding, and Monitoring and evaluation. Within these six areas, there are 25 standards and 283 indicators in total.

2.2 Accreditation frameworks governing higher education

For nearly two decades higher education in BiH is familiar with accreditation and accreditation standards. These were officially formalized in several iterations, and the current one [18] is from 2016. There are 10 criteria with 34 sub-criteria for accreditation of higher education institutions in Bosnia and Herzegovina. Accreditation is a legal requirement in some contexts (employment) but also a mandatory feature for the basic functioning of higher education institution. [19] The national agency is managing the process and keeping the Register of accredited institutions and study programs. The process and the register enable BiH institutions and their graduates recognition of qualifications, mobilities and international cooperation.

2.3 Accreditations in international frameworks

Accreditations in international contexts vary from virtually non-existent to strictly formalized, strong structures and control mechanisms. An EU Country example is Bulgaria that implements multi-level control mechanisms of quality assurance in early childhood and school education. Quality assurance is guaranteed through self-evaluations and inspections. [20] In Romania, there is The Romanian Agency for Quality Assurance in Pre-academic Education (ARACIP) that performs external evaluations of pre-university education. There are standards that identify 16 criteria, and for each criterion a varying number of performance indicators, with three types of external evaluations. [21] There are also common initiatives and joint frameworks, bringing us

to the situation where "several nations have standardized models and regulations on quality, despite lacking consensus on what quality is about." [22] Nevertheless, Finnish Education Evaluation Centre issued *Guidelines and recommendations for evaluating the quality of early childhood education and care*, containing factors and indicators that serve dual purpose, both ECEC institutions as providers of service and as tool for evaluating the structure and content of ECEC. [23] There are 34 indicators in the domain of 13 structural factors, distributed through national, local and level of pedagogical activities; and also 26 indicators in the domain of 7 process-related factors.

3. Analysis of domestic practices

Preschool education in Bosnia and Herzegovina operates within a complex and highly decentralized system, marked by significant regional variations in governance, access, resources, magnitude and quality. Despite growing recognition of the importance of early childhood education for lifelong learning and social equity, the sector remains unevenly supported across the country. Fragmented responsibilities between entities, cantons, and local authorities have led to disparities in policy implementation, curriculum development, and professional standards. This analysis provides a glimpse into domestic practices in preschool education in BiH, including dimensions such as access, curriculum, workforce development, inclusion and focusing more on quality assurance.

Early childhood education and care is regulated by laws and regulations, but in different ways across the country. Apart from national agencies and coordinating institutions, entity levels differ significantly since in RS entity, there is only one system, universally applied and managed centrally. In FBiH entity, there are additional cantonal ministries in charge of education, and local municipalities take part in provision of preschool education too. Common documents are created, but their intention is mainly to serve as guidelines. Quality Standards for Preschool Institutions Services somehow bashfully treat its own role, using wording as "if used for accreditation purposes." [17]

Even basic provision of access to early childhood education and care is not evenly distributed, following the economic development of local communities and/or large cities. With varying percentages of children attending preschool institutions, very positive is statistical trend of increased participation of children, from 6,4% in 2006 to 25% in 2020. [14]

Since preschool education providers in BiH are university graduates with at least bachelor's degrees it is meaningful to compare these two concepts, bearing in mind that one's practices and experiences influence their performance and understanding. [24] At the same time, collective influences lead to collective practices. Given the way educators ae introduced to the profession, it is just natural that previously established practices are first learned, then implemented and nurtured among colleagues. Yet, we are aware that changes are needed, but it is also evident that "teaching differently is a dangerous work." [25] After completing four-year secondary school one can enroll

teaching faculties, organized in various areas and models, with some local units requiring master's degrees. Only after completing an internship and passing a professional exam can one become a professional and work with children independently[36].

There are curricular initiatives for implementing common, or core common curriculum across as large as possible area but given the political misuse of every aspect of life, preschool education is not different. At the same time, there is awareness of differing needs, so the balance between unified and open, liberal concepts remains legal and acceptable across the country. Nevertheless, demands identified in national documents must be met. The goal is to have a child-centered approach implemented in all the institutions. There is a tendency that these institutions become qualified providers of services to children with special needs, even though, there is no legal obligation to provide for.

Quality Standards for Preschool Institutions Services somehow bashfully treat accreditation as the process, even though, it clearly states that they can be used for "accreditation and inspection." [17] Their role, as previously emphasized was to be a guideline, rather than norm for evaluation. In that context, only licenses from relevant authorities are required to operate a preschool institution.

3.1 Key challenges

EU Quality framework for Early childhood education and care (ECEC) identified 5 key components of a qualitative system. These are governance and funding, access, staff, curriculum, and evaluation and monitoring. [26] High-quality early childhood education and care lays the foundations for later success in life in terms of education, well-being, employability and social integration. It is especially important for children from disadvantaged backgrounds. [27]

So, it is conceptual design, implementation strategy and resource provision that pose challenges to quality preschool education. In BiH it is additionally complicated by numerous, uncoordinated educational levels, initiatives and agendas. Nevertheless, the ideal of free child, reaching their full potential and success, happiness and citizenship remains on the horizon.

3.2 Comparison of approaches

So far, we have discussed the notion of prescribed, state-initiated standards and accreditations. It is worth mentioning the other pole of this continuum, additional and specific standards, voluntary in nature that preschool providers secure and uphold. In Singapore, there is the Singapore Preschool Accreditation Framework (SPARK) that aims to provide recognition and support for preschool leaders in their efforts to improve teaching and learning, and administration and management processes to enhance the holistic development and well-being of young children [28] but also, there

is widely applied Healthy Preschool Accreditation, ran by Health Promotion Board aiming to promote healthy living through various programs. [29] There are also international accreditation programs and initiatives, such as International Association for Quality Assurance in Pre-Tertiary and Higher Education (QAHE) [30] or Cognia [31] that provides internationally recognized accreditation across the globe. The differences in approach within BiH are witnessed through the example of the two sets of accreditation criteria of HEIs and preschool institutions.

Table 1. Comparison of approaches within BiH.

Aspect	HEIs	Preschools
Implementation Body	State-level agency (HEA)	None nationally
Legal Framework	More harmonized	Highly fragmented
Evaluation Process	Institutional self-evaluation, external peer review	Rare or limited in most regions
Use of Standards	Aligned with European ESG	Varies by entity/canton, often incomplete
Transparency	Public reports exist	Often absent or unpublished
Focus	Academic quality, research, governance	Infrastructure, hygiene, staffing (less on pedagogy)

So, on one hand, we have the common origin of both documents, coming from the internationally established spheres, but differing in the fact that HEA standards were adopted from a single, purposeful document, the Standards and guidelines for quality assurance in the European Higher Education Area (ESG), while the preschool standards were developed as enlargement to the already existing policy documents in BiH and from various international sources. Hence the difference in volume and scope might come. Furthermore, the accreditation for HEIs can be implemented, while in the case of preschool institutions, it is not clear who would implement the accreditation process. Accreditation of HEIs is needed in terms of mobility and employability, while, no matter how, promotion to further education after preschool is guaranteed. However, the results will not be equal.

4. The future of preschool education in BiH

The future of preschool education in Bosnia and Herzegovina, particularly in relation to accreditation, lies at a crucial turn point. Although certain regions within BiH have made progress in setting operational standards for preschool institutions, the country as a

whole lacks a coherent, unified system of accreditation that would guarantee equal opportunities to all children. As a result, many children do not have equal access to high-quality early learning experiences, and institutions often operate without structured oversight of pedagogical quality or outcomes.

In the absence of a national framework, most forms of regulation focus primarily on licensing requirements such as facility conditions, hygiene standards, and staff qualifications. These are important foundations, but they do not encompass broader educational indicators like curriculum quality, child development outcomes, or inclusive practices. Accreditation, in the formal sense of assessing and recognizing the quality and effectiveness of preschool institutions, is not yet systematically applied. However, increasing awareness of the importance of early childhood education—both within government structures and among the public—has created preconditions for positive reform.

In the coming years, significant developments in preschool accreditation could be expected, particularly under the influence of international frameworks and EU integration. The 2019 EU Council Recommendation on High-Quality Early Childhood Education and Care Systems, as well as UNICEF-supported policy initiatives in BiH, have begun shaping expectations for more robust quality assurance systems. These include the development of measurable standards, self-assessment tools, external evaluations, and greater accountability mechanisms. Over time, such initiatives could evolve into formal accreditation models modeled after those used in BiH's higher education sector, where institutional self-evaluation, peer review, and standardized criteria have already been implemented with some success.

Nonetheless, several challenges must be overcome to realize this vision. Many preschool providers, particularly in under-resourced areas, may struggle to meet higher standards without adequate support and investment. Furthermore, quality assurance and accreditation require a shift in institutional culture—moving from basic survival or formal compliance toward a mindset of reflective practice, inclusivity, and lifelong learning starting from the earliest years.

In conclusion, the future of preschool education in BiH depends on the country's ability to build consensus around what constitutes quality, to support providers in meeting higher standards, and to develop a fair, transparent, and sustainable system for accrediting early childhood institutions. As global and European policy directions increasingly emphasize early learning as the foundation for lifelong success, BiH has both the opportunity and the obligation to create an accreditation system that ensures every child has access not only to preschool—but to a high-quality preschool experience.

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Process management

Mirsad Begić

TUV THURINGEN ADRIA d.o.o. Sarajevo, Bosnia and Herzegovina

E-mail: begic.mirsad@bih.net.ba

Abstract. With the adoption of new versions of standards for the development, maintenance, and continuous improvement of management systems (quality, environmental protection, safety, and health and safety of employees at work, as well as similar organizational management systems), the process approach to organizational management has been fully confirmed as a unique and very effective tool for effective management of an organization. The process approach to management is a horizontal approach to managing a network of processes that is significantly more efficient than the usual vertical approach based on a hierarchical organizational chart. The essence of the process approach is identifying processes (their essential elements: inputs, outputs, control points, connections with other processes, and monitoring, measuring, collecting, and analyzing data and continuous improvement). Process owners (the persons most responsible for the process) and connections between processes are identified so that process owners can immediately resolve any problems at the horizontal/lowest hierarchical level. For each process, key performance indicators (KPIs) of the process and specific measurable goals for each indicator are determined, through which the process owner manages and continuously improves his process and its performance. In this approach, the organization is viewed as a network of processes (a well-ordered and functional mechanism) through which customer requirements (at the input to the organization) are efficiently and effectively converted into outputs (the services or products that the customers at the input requested).

1. Introduction

The competitive global environment of the 21st-century market has heightened awareness of business processes as the most important management paradigm. The concept of process-oriented organization is increasingly being embraced, and the process-based approach is becoming essential for daily operations. In modern business practice, process management is key to the effective functioning and development of organizations, particularly in the manufacturing sector.

This topic outlines the importance of process management, identifies specific processes, tools, and challenges, and follows their implementation in real production environments. Integrating a process framework into the management structure means focusing on the consistent and cooperative achievement of results that directly impact

the operational level, while presuming satisfied customers and internally influential interested parties.

The management of individual processes, as well as the system of interrelated processes, is essential for the effective implementation of company policy and the achievement of both organizational and process-specific objectives. It is important to emphasize that processes must be subject to continuous measurement and analysis regarding their adequacy, effectiveness, and efficiency in fulfilling their intended purpose and goals. Continuous improvement of both processes and the system as a whole should be based on the results of these measurements and analyses, as well as other objective information and facts gathered during process execution.

2. Process-oriented approach

Process management involves the identification, analysis, planning, control, and continuous improvement of business activities that lead to the achievement of defined objectives. In manufacturing organizations, this means optimizing resources, improving quality, shortening delivery times, and reducing costs. The process-oriented approach replaces the traditional functional organization by shifting the focus toward value flow and outcomes.

Process orientation must encompass the following: identifying processes; determining the steps and interactions within processes; establishing characteristics, criteria, and methods necessary to ensure effective implementation and control of processes; assigning individual responsibilities for processes; defining the communication methods and information systems within and between processes; schematically representing the process network as a unified depiction of the organization's overall functioning; monitoring, measuring, and analyzing the effectiveness and efficiency of all processes and the organization as a whole; and continuously implementing improvements within processes.

By implementing this management approach, we achieve fact-based management derived from your processes, indicators of what we have accomplished and what our goals are, concrete metrics for decision-making on the next steps, motivation, and specific indicators for the continuous improvement of our processes.

3. Process and process approach

For an organization to function efficiently, it must identify numerous interconnected activities and manage them accordingly. An activity that uses resources and is managed with the intent of transforming inputs into outputs can be considered a process. The application of a system of processes within an organization, along with the identification and interaction of these processes and their management, can be referred to as the process approach.

A process represents a series of connected and interacting activities that transform input elements into output elements. Based on the above, we can say that a business process is a structured, analytical, cross-functional set of activities that requires continuous improvement. These activities have clearly defined beginnings and endings, during which value is created for customers at more or less constant intervals [4].

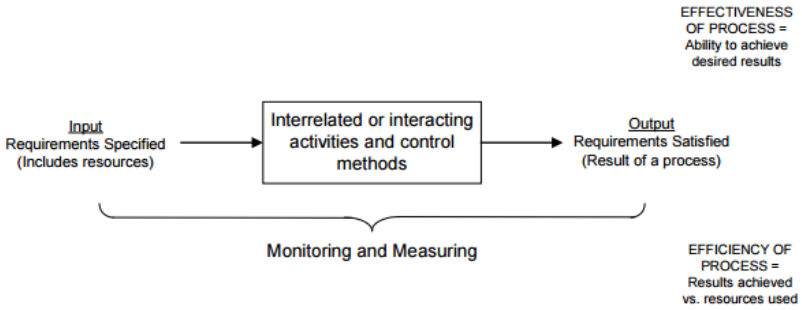

Figure 1. A generic process [10].

The process diagram (transforming Input into Output) involves the following steps:

1. The first step is the input, which must be defined, clear, and compliant with standards.
2. The second step represents activities with measurable characteristics and clearly defined answers to WHO, WHAT, HOW, WHEN, and WHERE to perform them; ensured with necessary resources, knowledge, and skills; established acceptance criteria; specific feedback loops. Each step should be verified to confirm its necessity and whether it can be performed more efficiently.
3. The third step is the output, which must be defined, clear, and compliant with standards

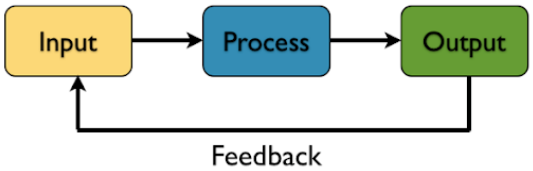

Figure 2. Transformation of inputs into outputs.

Key elements of the process approach:

• Process identification

This step involves recognizing and defining the key and supporting processes within the organization. The goal is to understand which processes directly impact the

achievement of business objectives and the delivery of value to customers. Key processes include production, service delivery, and customer support. Supporting processes include procurement, human resources, and IT support.

• Process mapping

Process mapping (process modeling) involves a graphical representation of the process flow, including: Inputs (resources, information), Outputs (results, products/services), Activities (process steps), and Roles and responsibilities. This enables better visibility and identification of potential points for improvement.

• Management of process interactions

In reality, processes never operate in isolation; the output of one process often serves as the input for another. Therefore, it is important to understand and manage the interactions between processes. The goal is to eliminate losses and delays, ensure clearly defined interprocess links, and, for example, the sales process depends on the production and procurement processes.

• Monitoring and measuring processes (KPI)

Each process should have defined performance indicators (KPIs – Key Performance Indicators) that enable an objective evaluation of its efficiency and effectiveness. Examples of process monitoring and measurement include process duration (e.g., order processing time), error rate (e.g., number of complaints), and customer satisfaction. Measurement allows decision-making based on data rather than assumptions.

• Continuous improvement

The process approach is closely linked to the philosophy of continual improvement (e.g., the PDCA cycle — Plan-Do-Check-Act). Based on the analysis of collected process performance data, the organization implements improvements aimed at increasing quality, efficiency, and customer satisfaction. Improvement tools include the Ishikawa diagram (cause-and-effect analysis), the 5 Whys analysis, and Lean and Six Sigma methods.

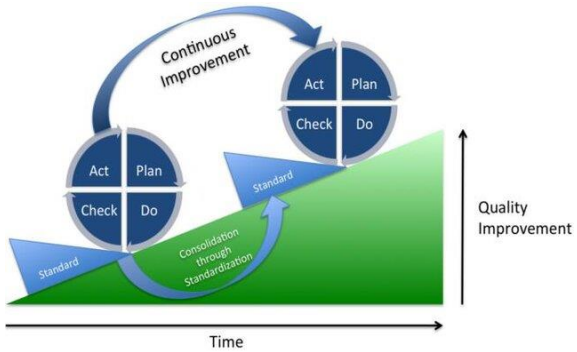

Figure 3. Continuous Improvement of ISO 9001 [9].

The most common consequences of poor business process management:

- Long lead times for product/service delivery
- High operational costs
- Inability to adapt to market changes
- Delays (missed deadlines)
- Ineffective decision-making
- Errors in task execution
- Poor product/service quality
- Inefficient use of resources
- Environmental pollution (lack of environmental care) and related consequences
- Dissatisfied customers and other interested parties
- Poor overall business performance
- Insolvency and further complications

Business process analysis must primarily address the following questions:

- What processes exist within the organization, and who are their "owners"?
- Which processes are critical for achieving the organization's strategic goals?
- Are the available processes adequate for achieving those strategic goals?
- What are the key weaknesses of the existing processes?
- What are the root causes of those weaknesses?
- What needs to be changed to eliminate the root causes?
- Who will be responsible for implementing improvements (How will the improvements be executed)?
- What indicators and metrics will be used to evaluate the success and effectiveness of the improvements?

Every organization should train its employees in the tools and methods used for process management. These may include:

• Flowchart - A flowchart is a formalized graphical method for process modeling, using standardized symbols to represent the sequential flow of activities, decisions, and the movement of information or materials. This tool is a fundamental instrument in process management, quality engineering, and business analytics, and its application contributes to greater transparency and process optimization.

- SWOT analysis of processes is a strategic tool used for the systematic evaluation of internal and external factors that influence processes. In the context of process management, SWOT analysis is applied to individual business processes or to a group of interconnected processes, with the aim of identifying opportunities for improvement.
- The Ishikawa diagram, also known as the cause-and-effect diagram or fishbone diagram, is a tool used to identify, organize, and display the possible causes of a specific problem or effect.

- The responsibility matrix is a tool used to clearly define roles and responsibilities within a project or process. It helps avoid misunderstandings about who is responsible for what and ensures that all team members are aware of their tasks.
- Key Performance Indicators (KPIs) are measurable values that organizations use to monitor and evaluate how successfully they are achieving their key objectives. They provide clear indications of whether goals are being met and support decision-making for improvement.
- The PDCA cycle (Deming Cycle) is a model for systematic problem-solving and continuous process improvement. It is used to plan, implement, check, and adjust activities.
- BPM software (Business Process Management) is a tool or a set of tools that help organizations design, model, automate, monitor, and optimize their business processes. The goal is to increase efficiency, reduce errors, and accelerate workflow.
- The Seven Supplier Questions Method is particularly suitable for resolving organizational or informational problems. It is based on the core model of the ISO 9001 standard, specifically the "customer–supplier relationship" (within the supply chain), where each party is simultaneously both a customer and a supplier, among other roles.

4. The Role of Management and Employees

The Role of Management in Process Management:

- Setting vision and goals: Management defines the strategy and key objectives that business processes should support.
- Process planning and design: Organizes and directs the creation and optimization of business processes.
- Resource approval: Provides the necessary resources (human, financial, technological) for effective process management.
- Monitoring and control: Oversees process performance, uses KPIs to measure success, and makes decisions on necessary improvements.
- Encouraging a culture of continuous improvement: Promotes initiatives for ongoing enhancement and innovation.
- Change management: Leads the process of adapting to changes in the business environment or technology.

The Role of Employees in Process Management:

- Task execution: Carry out activities within defined processes and adhere to standards and procedures.
- Problem identification: Are the first to recognize and report non-conformities, errors, or bottlenecks in the process.
- Providing feedback: Actively participate in suggesting improvements and innovations.

- Adopting changes: Adapt to new procedures, technologies, and ways of working.
- Collaboration and communication: Communicate within the team and with other departments to ensure smooth process flow.

5. Conclusion

The process approach enables manufacturing and service organizations to increase efficiency, improve quality, and better respond to market changes. Despite challenges, the benefits are significant when there is management commitment and employee engagement. Process management is not a simple task but a continuous strategic direction towards improvement and competitiveness. A shift to a process-oriented philosophy is necessary because customers are often more disappointed by poor business processes than by poor products or services. Every organization needs to determine the level of process orientation it requires and be aware that transitioning to a process philosophy is a long-term and comprehensive paradigm shift in business operations.

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Water quality of natural springs in the municipality of Bihac

Melisa Halilovic[1], Minela Cejvan[2] and Ekrem Pehlic[3]

[1] University of Bihac, Faculty of Health Studies, Bihac,
[2] University of Bihac, Faculty of Health Studies, Bihac, Bosnia and Herzegovina
[3] University of Bihac, Faculty of Health Studies, Bihac, Bosnia and Herzegovina

E-mail: melisa_zulic@hotmail.com

Abstract. Water, as a medium essential for human survival, must possess quality characterized by its physical, chemical and microbiological properties. The aim of this study was to determine the water quality parameters at natural springs in the municipality of Bihac, where regular water quality control analyses are not conducted, and to assess whether such water is suitable for drinking. Water samples were collected from eight locations at different altitudes. The physical-chemical analysis included parameters such as temperature, hydrogen ion concentration (pH value), electrical conductivity and oxygen saturation. The microbiological analysis was performed using the membrane filtration method and by inoculating samples on CCA (Chromogenic Coliform Agar) and SB (Slanetz Bartley Agar) to detect the presence of coliform bacteria and fecal streptococci. Analysis of the obtained data showed that locality Zalozje (above the mosque), locality Zalozje (near the mosque) and locality Srbljani (Hodzinovac) exhibited high electrical conductivity values along with an increase in coliform bacteria and *Escherichia coli.* The temperature in the examined samples ranged from 11.8 to 17.9 °C, pH from 7.27 to 7.67, electrical conductivity from 281 to 545 µS/cm, and dissolved oxygen from 7.2 to 10.7 mg/L. No presence of fecal streptococci was detected in the analysed samples.

Keywords: water quality, spring water, human consumption, contamination, Bihac

1. Introduction

Water is one of the most vital natural resources and a fundamental prerequisite for the survival of life on Earth. Its availability and quality have a direct impact on public health, economic development, food production, ecosystem preservation, and overall social stability [1].

Despite the fact that approximately 70% of the Earth's surface is covered by water, only 2.5% of it is freshwater, and less than 1% is readily accessible for direct

human use [2]. Therefore, the rational use and protection of this resource are of crucial importance, particularly in local communities that heavily rely on natural water sources. The global demand for safe drinking water is continuously increasing, primarily due to the intensifying pollution of water bodies caused by rapid population growth and expanded anthropogenic activities. According to the World Health Organization (WHO) and UNICEF, 2017., approximately 29% of the global population lacks access to safely managed drinking water, and one in three people living in rural areas does not use water that meets safety standards. Spring water, simply put, is groundwater that emerges at the surface through natural openings, thereby becoming surface water.

The quality of the groundwater that emerges as springs largely reflects the geological and environmental characteristics of the area from which it originates. Although spring water is often considered safe for drinking among surface water sources, this assumption is not entirely accurate. While underground, water absorbs natural minerals as well as naturally occurring metals from the soil, some of which may have serious adverse effects on human health. Therefore, it is essential to regularly monitor and protect these water sources to ensure healthy living conditions and a sufficient supply of safe drinking water [3]. In many parts of the world, spring water is considered a valuable source of drinking water. Climate change, particularly the decrease in precipitation, along with human activities such as agriculture and urbanization, are regarded as major factors contributing to reduced spring discharge [4]. Furthermore, springs are rapidly disappearing globally due to the lack of adequate management and conservation measures, especially in arid regions [5]. In many parts of the developing world, large populations rely daily on natural water sources for essential needs such as drinking, cooking, hygiene, and irrigation. The quality of these waters often remains unverified, and due to increasing anthropogenic pressures such as agriculture, industrial activity, improper waste disposal, and climate change deterioration in the quality of these sources is frequently observed [6]. Contaminated water directly contributes to the spread of diseases such as diarrhoea, cholera, dysentery, hepatitis A, and typhoid, causing millions of deaths each year, primarily among children [7]. Bosnia and Herzegovina possesses significant quantities of surface and groundwater, yet unequal infrastructure development and institutional limitations often hinder effective management and water quality control. It is estimated that only about 65% of the population has access to public water supply systems, which is significantly below the European average [8].

Rural areas, including parts of the Bihac municipality, frequently rely solely on local natural water sources—such as fountains, wells, and springs without continuous monitoring or regular analysis of their chemical and microbiological composition. The municipality of Bihac, located in the Una-Sana Canton, is rich in water resources, including numerous rivers (Una, Klokot, and Krusnica), springs, and groundwater. However, the available data on the quality of these waters is fragmented and often

outdated, while in practice, a systematic approach to monitoring and source protection is lacking. Inadequate management of septic tanks, agricultural fertilization, and increasing urban pressure present additional risks of resource contamination [9]. The aim of this paper is to investigate the quality and health safety of natural spring water in the municipality of Bihac by analyzing physical-chemical and microbiological parameters. Based on the obtained data, the study will provide recommendations for preserving spring water quality and improving local water policies with the goal of protecting public health and preserving the environment.

2. Methods

In order to assess the health safety of natural water springs, samples were collected from eight locations within the municipality of Bihac. The sampling was carried out in early May 2025. A water sample for physical-chemical analysis was collected in a clean glass bottle with a volume of 1.5 liters, while the sample for microbiological analysis was collected in a sterile glass bottle with a volume of 1 liter. Subsequently, physical-chemical and microbiological analyses were conducted in the laboratories of the Faculty of Health Studies.

2.1 Physical-chemical analysis

The physical-chemical analysis was conducted based on in situ measurements using a multiparameter device (PCE 228).

Measurements of temperature, pH, electrical conductivity, and dissolved oxygen were performed at the selected locations.

2.2 Microbiological analysis

The microbiological analysis was performed using the membrane filtration method. Under sterile conditions, 100 ml of the water sample was passed through a filter paper with a pore size of 0.45 μm using a vacuum pump connected to the membrane filtration apparatus. The filter paper was then transferred to a sterile Petri dish containing nutrient medium.

The total number of coliform bacteria was determined by inoculating the filter paper onto CCA agar (Chromogenic Coliform Agar), while the total number of fecal streptococci was determined using SB agar (Slanetz - Bartley Agar). After 24 hours of incubation at 37 °C, the results were read. The presence of coliform bacteria was confirmed by the Indole test.

3. Results

In table 1. we can see that the physical-chemical analysis of spring water samples was conducted at eight locations within the municipality of Bihac. The analyzed parameters

included temperature, pH value, electrical conductivity, and dissolved oxygen concentration.

The water temperature ranged from 11.8 °C (Srbljani – Hodzinovac) to 17.9 °C (Brekovica – Kljucka water), reflecting differences in elevation, spring depth, and shading of the terrain.

The pH values ranged from 7.27 to 7.67, indicating a slightly basic reaction of the water, which is typical for natural springs in this region.

Electrical conductivity, which reflects the presence of dissolved ionic substances in water, varied between 293 µS/cm (Brekovica – Kljucka water) and 545 µS/cm (Ostrozac). These values fall within the expected range for spring water but indicate some variation in mineral content between locations.

Table 1. Results of physical-chemical analysis.

Locations	Parameters			
	Temperature **^{0}C/F**	**pH**	Electrical conductivity **µS/cm**	Dissolved Oxygen **mg/l**
Međudrazje	13,2	7,67	325	10,1
Zalozje (above the mosque)	12,5	7,60	329	9,4
Zalozje (near the mosque)	13,4	7,27	457	7,2
Srbljani (Hodzinovac)	11,8	7,49	430	9,1
Ostrozac	14,2	7,62	545	9,6
Brekovica (Kljucka water)	17,9	7,49	293	10,7
Brekovica (wheel)	16,3	7,45	297	7,4
Brekovica (side)	15,7	7,62	320	8,3

The concentration of dissolved oxygen was lowest at the Založje (near the mosque) location – 7.2 mg/L, and highest at Brekovica (Kljucka water) – 10.7 mg/L. Higher values indicate good aeration and the absence of pollution, while lower values may suggest microbial activity or water stagnation. All measured values are generally within the acceptable limits for drinking water according to the World Health

Organization (WHO) guidelines, indicating relatively good water quality from a physical-chemical perspective, with some local variation.

Based on the microbiological analyses conducted, the results indicate that coliform bacteria were detected in three out of the eight water samples. In cases where the presence of coliform bacteria is suspected (evidenced by bluish colonies) on CCA agar after incubation, the Indole test is conducted to confirm the presence of coliform bacteria, specifically Escherichia coli. The selected colonies are inoculated into tryptophan broth and incubated at 35-37°C for a period of 24-48 hours. Following incubation, Kovac's reagent is added to the broth, and the upper layer in the test tube is observed. A red-pink color at the surface indicates a positive result. Figure 1.2.3. The locations contaminated with coliform bacteria also had higher electrical conductivity.

Figure 1. Positive results of the indol test at location 2 (Zalozje-above the mosque).

Figure 2. Positive results of the indol test at location 3 (Zalozje-near the mosque).

Figure 3. Positive results of the indol test at location 4 (Srbljani-Hodzinovac).

These findings suggest potential contamination of the water with fecal matter, which poses a significant health risk to consumers who use this water without proper treatment. Fecal streptococci, which are also used as indicators of fecal contamination, were not detected in any of the samples, indicating that there was no significant contamination with animal feces, at least not at levels detectable by this method.

4. Conclusion

The study of the quality of natural spring sources in the municipality of Bihac covered eight locations, with the aim of determining the health safety of the water for human consumption. The results of the physical-chemical and microbiological analyses showed that water from most of the investigated springs is of satisfactory quality and complies with the current standards for drinking water.

However, the presence of coliform bacteria was confirmed at three locations, indicating possible fecal contamination, most likely of animal origin. Such microbiological pollution poses a significant health risk, especially when the water is consumed without prior disinfection or boiling. Therefore, it is essential to urgently inform the local community of the potential health hazard and involve the relevant authorities to identify the sources of contamination and implement appropriate protection measures. Additionally, the findings highlight the need to establish a regular monitoring system for spring water quality, in order to ensure long-term public health safety and to preserve the value of natural water resources in the area.

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Digital Technologies in beekeeping

Azira Hrnjica[1], Melisa Oraščanin[2] and Edina Šertović[2]

[1] Faculty of Health Studies, University of Bihac, Bosnia and Herzegovina, Bihac
[2] Biotechnical Faculty, University of Bihac, Bosnia and Herzegovina, Bihac

E-mail: edina.sertovic@gmail.com

Abstract. Beekeeping, in which, in addition to the traditional concept, digital technology tools are also used, is called precision beekeeping or digital beekeeping. The hives in this context are called smart hives. Beekeepers around the world are increasingly adopting digital tools, and a wide variety of technological solutions for the modernization of beekeeping are available on the market. The aim of this paper is to present some of the digital tools that have already been assimilated in beekeeping, but also to the latest initiatives in this field. Manual opening of hives and visual inspection can have negative effects on the bee colony itself. By installing smart hives, these negative effects can be avoided, and additional benefits can be achieved. Some of the basic advantages of the application of technologies in beekeeping are continuous monitoring of the condition, prediction of diseases, and quick and timely action. The transition to digital beekeeping is called Beekeeping 4.0, and it represents a parallel with the concept of agriculture 4.0. This refers to the automated collection, unification and analysis of data from hives, as well as external parameters from the environment. The research initiatives B-GOOD and EU HIVEOPOLIS are funded by the European Union and have a major contribution to the development of technologies useful for sustainable beekeeping. Their research represents the basis for further assimilation of digital technologies in the real beekeeping sector. "Beehold" and "Fitnet" are examples of companies that are actively engaged in the transition of traditional beekeeping to digital by operating in the territories of Bosnia and Herzegovina and Serbia, with an affinity to expand to the European market. It can be concluded that digital technologies are inevitable in the future of sustainable beekeeping and are useful for beekeepers to obtain a higher yield, but also to preserve biodiversity.

1. Introduction

Bee colonies around the world are declining. Some factors behind the decline are known, while others are still being investigated. The ultimate cause of the global bee decline is considered multifactorial and has not been fully investigated. This makes it even more difficult to find solutions to reduce bee extinction.

Beekeeping is considered part of agriculture. In order to increase the yield of bee products and to better manage bee colonies, beekeepers should embrace the concept of Beekeeping 4.0. This concept enables the automated collection, integration and analysis

of data from hives, as well as monitoring of the landscape and weather conditions. This concept requires a shift from traditional beekeeping practices to beekeeping enhanced by digital systems, with benefits including cost reduction, greater profitability and environmental, social and economic sustainability of agriculture [1].

Academic studies and literature on the application of technologies, Internet of Things (IoT) and Decision Support Systems (DSS) in beekeeping are very limited and have only recently become the focus of many researches including electrical engineering, engineering, electronics and information systems research in beekeeping [2].

The aim of this paper is to emphasize the advantages of the application of technologies in beekeeping and to emphasize the importance of each individual technology that has been applied so far, and which has given good results. In addition, the paper highlights the efforts that the European Union is making to reduce the extinction of bees and to assimilate digital technologies in beekeeping as efficiently as possible.

2. Causes of bee decline worldwide

Bees pollinate 84% of plant species that are essential for human nutrition, directly contributing to the production of one third of the food consumed by humans [3]. Bees are dying out worldwide, affecting ecosystems and agriculture.

In the United States, beekeeping has been losing up to 40% of its bee colonies annually since 2007, in the United Kingdom 10-30%, in Austria 25%, while in Russia the loss of honey bees is 20%. For Russia, climate dependence is particularly high, and only 1/3 of the land area is considered effective for beekeeping.

Beekeeping in Siberia is particularly difficult due to the difficulty of organizing bee wintering when temperatures drop to -50 °C. On the other hand, spring is cold and rainy, and the honey harvest time is short, 2-3 weeks, which overall leads to the greatest decline of bees in the world (3). A National Survey on Winter Mortality of Bee Colonies was conducted in France during the winter of 2020–2021 with more than 13.000 beekeepers participating. Overall, the mortality rate was estimated at 24.8% [4].

The underlying cause of bee decline is climate change, with extreme weather conditions making it difficult for bees to find food and maintain colonies. Urbanization is also considered to be one of the causes, reducing pollen and nectar sources for bees, which also causes problems for bee colony maintenance in terms of limiting natural food sources. Agriculture is also one of the causes of bee decline due to monoculture farming practices, which cause limited food resources for bees [2]. Additional causes of bee declines are not yet fully understood, which further complicates the solution to the current problem. This phenomenon is called Colony Collapse Disorder (CCD).The phenomenon, known as bee collapse disorder, was first identified in 2006. Since then,

some European countries have reported losing around a third of their colonies in one winter [2].

Varroosis disease, which is transmitted by the Varroa mite, is also considered a possible cause of the death of bees. It should be noted that the greatest extinction of bees is observed in industrialized countries. Due to all of the above, the production of bee products decreased [3].

3. Overview of different technologies that can be integrated in beekeeping

The primary technologies on which modern beekeeping are based experienced rise between 1850 and 1875, with the development of the beehive with a movable frame and the centrifugal honey extractor.

Now is the era of smartphones and the Internet, and beekeeping is in the course of a new revolution in which technology is changing beekeeping as it exists today [5]. At the base of beekeeping 4.0 lies the concept of industry 4.0. Industry 4.0 represents the fourth industrial revolution, and it has 4 basic items that differ from previous revolutions, namely sensors, data, information and processing elements. Additional characteristics of beekeeping 4.0 are data security, data analysis, artificial intelligence and cloud computing. The afore-mentioned technologies, when implemented in beekeeping, can contribute to economic and ecological prosperity: they can help in the early detection of diseases in bee colonies, and help in finding food, and pollination of plants. This can consequently lead to meeting food needs, raising the standard of living of beekeepers and ensuring beekeeping development.

Digital technologies can be introduced into all aspects of beekeeping, and benefit people, bees and the ecosystem. It is often emphasized that the digital transformation movement in beekeeping should connect traditional beekeeping with modern technologies, which will enable better control of hives, maintaining bee health and increasing honey yields [2]. The extent to which beekeepers are willing to invest in technological solutions in their apiaries depends on the beekeepers' own needs, the size of the apiary, technological skills and literacy and financial capacity to invest.

There are a large number of technologies on the market, some of which are more suitable for small beekeepers whose yields are limited to household needs or slightly larger, while other sophisticated technological solutions are available for implementation by technically savvy beekeepers that are willing and able to invest significant financial resources regardless of the size of their apiaries [6]. A critical review of the trend of increased implementation of digital technological solutions in beekeeping should be highlighted here. Most of these technologies are energy intensive because they require the mining of increasingly scarce minerals. It should be emphasized that the current ability to use new energy sources and continue to produce and distribute energy from current sources (primarily fossil fuels) is decreasing faster.

The current fast and cheap sources of fossil fuels are decreasing and require the development of non-conventional energy sources [5].

4. Precision beekeeping and smart hives

The emergence of the ''smart hive'' is one of the aspects of the technological revolution. It is a hive that is wired with sensors that monitor and measure hive weight, brood temperature, relative humidity inside the hive, weather conditions and many other parameters. All this data can be collected and transferred to any device that has access to the Internet [5].

Precision beekeeping is a branch of precision agriculture and is based on monitoring individual bee colonies to maximize bee productivity by seeking to solve challenges at two main levels: the apiary level and the community level [7].

Precision beekeeping refers to the control of hives to gather useful information for the beekeeper. Controlled parameters are bee flight activity, hive temperature, humidity and hive weight. Technologies can provide accurate information in real time that can prevent diseases of bee colonies and improve their health, increase yields of bee products, and reduce costs and negative impacts on the environment [6]. The results of an Ethiopian study show that modern hives produce a higher honey yield of 18,03 kg compared to traditional hives, which produce a yield of 5,15 kg. This study clearly indicates that the average annual income is significantly higher due to the higher honey yield from modern hives compared to the income obtained from honey from a traditional apiary [2].

The basis of digital beekeeping are the sensors built into hive that make hives smart. Sensors continuously collect data on weight, temperature, humidity, number of entries/exits, and pollination activity.

The application of sensors in beekeeping also has challenges that need to be overcome. These challenges relate to their ability to function in harsh weather conditions and to meet power requirements in remote or rural areas with limited electricity supply. The adoption of Digital Beehive Monitoring Technology is lower in northern European countries, as cold weather conditions are likely to affect battery life [1]. On the one hand, opening hives for the purpose of physical inspection of the condition of the bees can disturb the bee colonies, whereas on the other hand it requires certain efforts of the beekeeper himself, especially in cases of control of hives located far from the place of living, which will cause financial and time losses.

It is common that the proportion of the number of hives that are digitally monitored decreases as the size of the beekeeping increases. This means that beekeepers with a larger number of hives opt for 'model' or 'indicator' hives for monitoring where only one or few hives per apiary or location are equipped with sensors instead of equipping each individual hive. This approach is selected by beekeepers who have decided to introduce technologies in their apiaries from the point of view of cost effectiveness [1].

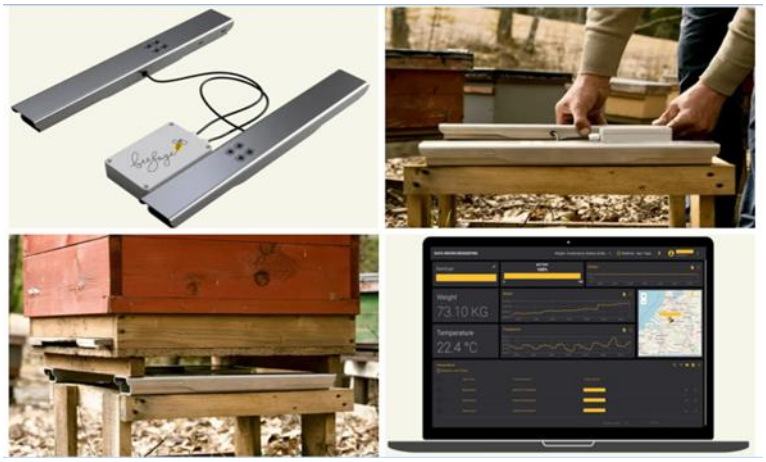

Figure 1. Smart hive scales for efficient monitoring of bee colonies. Data on weight, ambient temperature and location are monitored and read once an hour. [8]

Industry 4.0 is based on different technologies, the main ones being IoT, Cloud Computing, Big Data and Cyber-Physical Systems (CPS). IoT is most often explained as a series of interconnected devices that can communicate with each other, i.e., as a technology and environment in which sensors are placed on various objects, with the possibility of sharing data in real time via Internet connectivity. Any device that has the ability to connect to the Internet can be considered an IoT device; for example, household appliances or surveillance cameras.

IoT (Internet of Things) in beekeeping implies the use of network-connected sensors, devices and software that automatically collect, send and analyze data from the apiary. The most common IoT devices in hives are: weight sensors, temperature and humidity sensors, microphones, cameras, GPS devices, WiFi modules and others [9].

4.1. Weight Sensors

The sensors used in beehives are hive weight sensors that can continuously measure the weight of the hive. Many beekeepers introduce technology into their apiaries to monitor only one parameter, mainly hive weight, and only on a limited number of hives. Hive weight is a good indicator of whether a colony will survive the winter. Bees need honey to survive the winter, and if they do not have enough honey, they leave the hive in search of food and are exposed to extreme winter weather conditions, which can lead to their death [10].

4.2. Temperature sensors

There are smart scales on the market that simultaneously monitor several parameters such as hive weight, ambient temperature and location, and provide updated information every hour (Figure 1). These sensors provide beekeepers with information about honey production by the bees. There are temperature and humidity sensors that

provide information about the temperature and humidity level inside the hive, which gives beekeepers an insight into the living conditions of the bees inside the hive [2].

The European Union allocates significant funds for scientific initiatives in the field of research into the extinction of bees, finding solutions for the survival of bee colonies in critical conditions, and the application of digital technologies in beekeeping. Thus, ''Hivepolis'' was a research initiative that lasted until 2019, headed by Schmickl and his collaborators who created a digital honeycomb equipped with sensors, called digital combs. This highlights the importance of measuring temperatures at different points in the hive so that beekeepers can identify where the brood or the brood nest are located in the hive.

When beekeepers know where the brood nest is located, they can open the hive without disturbing this sensitive area. The sensors created in this research initiative can be activated to heat specific parts of the hive, which could affect survival rates, as many bees die from the cold in winter when they leave the hive trying to reach food. Sensors that help keep bees warm during the winter could increase the survival rate of colonies.

The experiments in this study showed that the colonies responded positively and that the intelligence of the bees responds to changes in temperature by reducing their own heat production, helping them save energy [10]. In addition, Varroa reproduction occurs at temperatures between 32.5 °C and 34.5 °C, so in this context, temperature monitoring and modeling is also important from the aspect of preventing bee colony diseases [11].

4.3 Humidity sensors

Bees are highly dependent on optimal humidity levels for their survival, especially during the winter months, as inadequate humidity can lead to colony collapse. Humidity is essential for the dilution of the honey they feed on and for brood development, and it also helps to reduce the reproduction of mites such as Varroa, whose activity is linked to humidity levels. On the other hand, too high humidity creates conditions for the development of harmful fungi that can damage hives during wet winters [6].

The relative humidity in a beehive during winter that is considered optimal for bees is between 50% and 80%. This humidity level allows for proper gas exchange and reduces the risk of fungi that pose a threat to bees. In addition, condensation of water due to excessive humidity causes cold droplets to fall on the bees, which can lead to mortality. At the same time, a lack of moisture can make honey too dry [12].

4.4 Noise sensors and applications to prevent colony collapse

Changes in sound frequencies and amplitudes can be indicators of swarming or the presence of a queen bee. What further disturbs bees is vibration or shaking. Noise sensors provide information about bee behavior by measuring their buzzing and other sounds. Microphones can be placed at specific locations inside or outside the hive.

Bees become agitated by these disturbances, and if the shaking continues for too long, it can break their brood nest. When this happens, the bees spread out throughout the hive and are at risk of freezing to death [13]. Likewise, by analyzing sound frequencies, phenomena such as swarming or the presence of a queen bee can be

detected [6]. Bromenshenk and a group of fellow university bee experts have developed an application that is in the final stages of testing. It is an application that uses artificial intelligence to analyze the sound of the buzzing of bees in order to conclude whether they are suffering from some disease or not. They studied sound recordings of bee colonies in their worldwide network of beekeepers. The entire base of sounds enabled the development of artificial neural networks. The created artificial neural network is used to recognize certain patterns and create algorithms that could connect sounds related to certain problems in the hive [14].

4.5 Camera sensors and image recognition

Camera sensors are used to monitor bee activity and movement within the hive and provide beekeepers with information on bee health and productivity. Furthermore, image analysis can be used for early diagnosis of diseases in bees. Changes in the color of bees can be signs of disease. Microscopic images of bee bodies and wings can be taken and these images can be analyzed with computer vision algorithms. This image processing can reveal signs of disease through image analysis algorithms that can be developed to recognize disease symptoms using cameras that scan bee bodies [2].

A practical example of the application of image recognition is the classification of images of bees into those containing Varroa mites or not. Abban et al. (2022) presented an innovative digital solution for the automated recognition and monitoring of the presence of varroa [15].

Traditional varroa counting methods rely on manual labor, making them demanding and error-prone. In response to this problem, the authors developed a system based on deep learning, which uses two neural networks: *Faster R-CNN* for detection of bees in images, and *U-NET* for image segmentation with the aim of identifying varroa on individual bees (Figure 2).

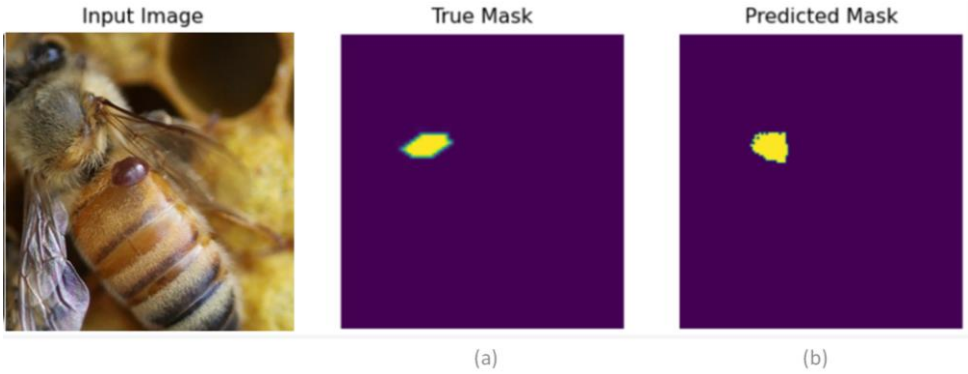

Figure 13. Varroa segmentation by U-NET. The yellow region represents varroa. (a) True Mask is ground-truth segmentation (b) Predicted Mask is the predicted segmentation. [4]

The infestation percentage can be calculated based on these data: the ratio of the number of infected bees to the total number. For the purposes of examining the model,

image data obtained from various sources were used including project partners, cameras and the Internet. The images were manually annotated, which means that specific labels were given to individual parts of the image manually in order to clearly indicate what is on them. Essentially, this means giving meaning to the pixels of the image so that the algorithm ''learns'' to recognize these objects [4].

Another potential application of image recognition technology is the recognition of honey bees carrying pollen. Due to the pictures of bees taken at the entrance to the hive, toxic materials and fake pollen can be detected in time [6].

Furthermore, pollen balls that are collected from tongs and then manually sorted by color can be automatically identified with computer vision. This is useful for laboratories that conduct beekeeping analyses, but also for beekeepers and researchers. Photos of pollen balls can be uploaded to a server via a suitable web application so that pollen balls can be identified in the image using object detection algorithms, such as Faster RCNN (Figure 3) [16].

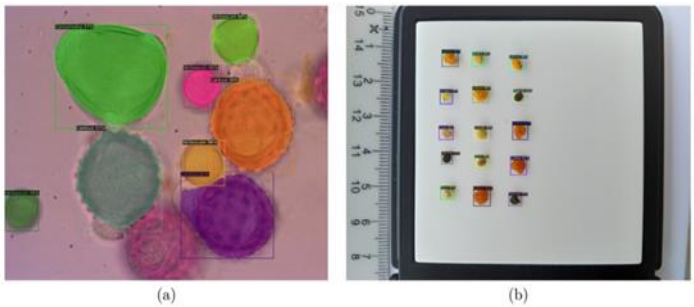

Figure 14. Identification of (a) pollen grains from microscope images and (b) pollen pellets from camera images. [16]

4.6. Development of predictive computer models in precision beekeeping

Although precision beekeeping is rapidly developing, scientists have not yet fully developed robust predictive models that would allow for reliable prediction of key variables within hives, such as temperature, humidity or weight. The development of such models is complex because it involves processing large amounts of multidimensional and interconnected data that change over time, and also needs to take into account external conditions such as weather.

By introducing precise predictive models, beekeepers would gain a powerful tool for early identification of problems in the hive, such as diseases, food shortages or changes in bee behavior. This would allow them to react in a timely manner without the need for frequent physical inspections, which saves time and reduces stress for the bees. For the bees themselves, this would mean more stable conditions in the hive, better protection from external threats and a higher chance of survival and productivity. Ultimately, the development of these models represents an important step towards more sustainable, efficient and humane beekeeping, in which technology works in the service of bee colony health and support for beekeepers. Therefore, there is research aimed at developing predictive models for precision beekeeping. Among

these investigations, a study stands out in which multivariate models, including autoregressive state and time series models, were implemented to predict the internal variables of the hive (temperature, humidity and weight) using the meteorological conditions to which the hive is exposed [11].

Models based on vector time series showed superior performance in forecasting internal hive variables compared to multivariate autoregressive state models. Overall, the approach based on the vector error correction model provided the best balance between adaptation, prediction and computational cost [11].

5. 3D printers in beekeeping

3D printers can be used in beekeeping to create equipment for beehives, sensor circuits and feeding equipment. 3D printing provides the possibility to imitate natural structures.

The design of a 3D printed honeycomb model, made using Autodesk Fusion 360 software, based on the natural honeycomb Apis cerana indica, is presented. This 3D printed honeycomb designed using a Raise 3D printer is made of acrylonitrile butadiene styrene filaments, and production parameters are optimized to balance the mechanical properties (Figure 4) [17].

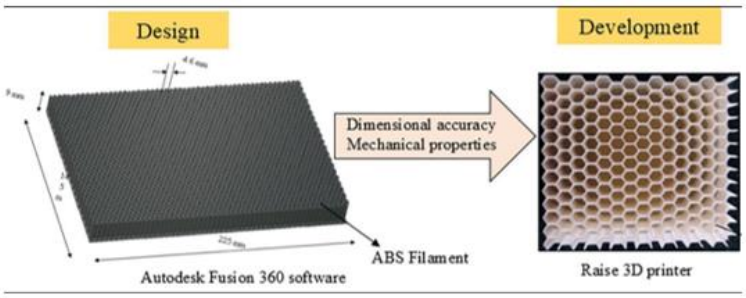

Figure 15. Creating a 3D printed honeycomb using Autodesk Fusion 360 software and designing using a Raise 3D printer. [17]

Practical examples of field tests were recorded that showed the successful production of honey by bees on 3D printed honeycomb. Natural combs are built by bees from wax through hard work, and in doing so, they consume significant energy and resources. This reduces the time and potential of the bees that they can devote to pollination and honey production. In addition, natural wax honeycomb has poor mechanical properties. It is subject to damage during honey extraction and in the honey centrifuge. Natural honeycomb is also subject to the influences of the external environment, microbial contamination, and the big wax moth poses a big threat. These properties mean that the natural honeycomb can be reused a maximum of 2-3 times. For this reason, alternative solutions such as 3D printed honeycombs, which can reduce stress in bees and improve overall efficiency, should be further researched and perfected [17]. Beekeepers in Russia, Canada and the United States often use plastic honeycombs and plastic frames, which belong to modern technical tools. The use of plastic honeycombs has many

advantages, some of which are: it does not have to be welded to the frame, it bears a greater load, losses from moths are smaller, honeycombs have a more regular shape and do not change under the weight of the honey and can be reused [3].

6. Research initiatives for the development of digital beekeeping in the European Union

Research was conducted on the adoption of digital technologies by 844 bekeepers in 18 European countries, examining their current patterns of use as well as the factors influencing the adoption of technologies [1]. The results showed that 79.1% of the beekeepers interviewed had not yet accepted any form of digital monitoring. However, 20.9% had some form of digital hive monitoring, but this was mainly related to weight monitoring. This study provides a timely insight into how the European beekeeping sector is developing in the direction of digitization, i.e. Beekeeping 4.0. This is happening at a time when the sector is approaching the so-called threshold of 25% adoption of new technology, a limit that is often considered a significant social milestone in innovation theories. This is the point that marks the end of early adoption and the beginning of entering the ''early majority'' - the group that accepts technology when it is no longer experimental, but ubiquitous. After that point, the technology usually starts to expand exponentially [1]. The B-GOOD project, part of a European research initiative funded by the EU, brought together a research team led by de Graaf, who, together with colleagues from 13 European countries, worked from 2019 to 2024 to develop digital solutions to preserve bee health and the sustainability of beekeeping.

The researchers developed a hive health monitoring system that not only detects potential problems within the colony, but also provides beekeepers with personalized recommendations for intervention. Over three consecutive seasons, almost 400 bee colonies were monitored in all 13 participating countries. This data was used to build algorithms for predicting and interpreting colony health. It was also discovered that hive weight is one of the key indicators of a bee colony's winter survival. The next phase of this research project focuses on analyzing and interpreting the collected data. The project works closely with the *EU Bee Partnership* – a platform established in 2017 to monitor bee health and share data at the European Union level. The EU continues to provide ongoing research funding under the new B-BETTER initiative, which will run until May 2027 [10]. The aforementioned ''Hivepolis'' team is currently researching a new innovative way to communicate with bees.

This research builds on the scientific foundations laid in 1973, when Karl von Frisch was awarded the Nobel Prize for his discovery of the waggle dance, a form of communication by which bees indicate the direction and distance of food sources. Von Frisch determined that information is transmitted through the angle of the dance in relation to the sun, the intensity and duration of the movement, allowing bees to precisely communicate their locations to foragers in the colony. Building on this foundation, Dr. Tim Landgraf, professor of Artificial and Collective Intelligence at Freie Universität Berlin and one of the partners in the ''Hivepolis'' project, has made significant advances in this field. He and his team have developed a robotic bee,

RoboBee, capable of performing a waggle dance in the hive. Experiments show that bees can accept and follow RoboBee's instructions, which represents a revolutionary advance in human-technology-animal interaction. The Hivepolis team believes that such robots could have practical applications in the future in guiding bees towards safe food sources, avoiding contaminated or dangerous areas, such as those exposed to pesticides or infected with diseases. This approach could play an important role in protecting the health of bees and improving the sustainability of beekeeping in an age of environmental challenges [10]. The current and interesting project ''SmartBeeKeep'', co-financed by the EU and Greece, is developing an integrated platform that uses remote monitoring and artificial intelligence to support beekeepers and researchers. The platform includes automatic mapping of beekeeping flora using Sentinel-2 satellite data and AI models, as well as web and mobile applications for hive management and plant identification through photographs. This project also includes work on the e-market for beekeeping products [14]. Beehold is a Serbian technology company based in Niš, specializing in the development of smart solutions in beekeeping based on artificial intelligence. Beehold successfully cooperates with beekeepers in Serbia using AI devices. In 2024, through UNDP's innovation support program, Beehold entered into a partnership with Fitnet-Online d.o.o. Mostar. Fitnet is a small Bosnian-Herzegovinian IT company specializing in services in the field of telecommunications and digital transformation. As a result of this cooperation, 30 apiaries in Bosnia and Herzegovina use the digital beekeeping system. These two companies are planning joint expansion into European markets and further development of a hardware-software solution to increase productivity. Fitnet has also developed digital services such as ''Reserve Your Honey'', ''Find Your Beekeeper'' and ''BeeConnect'', a platform for sharing beekeeping resources and products [18].

Conclusion

Traditional beekeeping methods are faced with the challenges of the global bee extinction due to climate change, pesticide use, disease and environmental degradation. Modern beekeeping can no longer rely exclusively on these methods. The introduction of digital technologies, such as smart hives, sensors and artificial intelligence, represents a key step towards more sustainable, efficient and informed beekeeping.

Precision beekeeping, supported by the development of IoT solutions, enables the monitoring of vital parameters of the colony, timely identification of risks and optimization of apiary management.

Weight, temperature, humidity, and noise sensors, as well as image recognition systems, integrated into comprehensive platforms, enable beekeepers to make decisions based on data, instead of assumptions. It is particularly encouraging that today's Europe has reached almost 25% of the so-called ''social milestones'' in the acceptance of technology in beekeeping, which represents a threshold after which a significantly faster and wider adoption of innovations within the sector is expected. This data indicates an accelerated transition from experimental to operational digital solutions, which are becoming the new norm in practice. European initiatives such as B-GOOD, HIVEOPOLIS and SmartBeeKeep show the potential of an interdisciplinary

approach in bee conservation. These research initiatives connect scientific institutions, technologies and local beekeeping communities. A regional example is the partnership between Serbia's Beehold and Mostar's Fitnet, which show how local solutions, with the support of international programs such as UNDP, can have a concrete impact on modernization and the spread of innovations in the sector.

In the future, it will be crucial to ensure that digital solutions remain accessible and adaptable to different types of beekeeping practices: both professional and hobby beekeepers. It will have to be continuously monitored so as not to lose sight of the importance of an ecological approach and the preservation of biodiversity. The digital transformation of beekeeping shows a comprehensive process and strategic approach that integrates advanced technologies, such as sensors, predictive models and innovative products of methods such as 3D printing, with the aim of optimizing beekeeping practices. Through this transformation, beekeeping becomes more resilient and efficient, allowing for more precise monitoring and better understanding of the needs of bee colonies. Finally, this approach is critical to protecting bees, one of the most important pollinators, thereby directly contributing to the preservation of global food security.

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Evaluation of the development of the food pyramid

Dženita Mustafić[1] and Suzana Jahić[2]

[1] ProNutricia, Sarajevo, Bosnia and Herzegovian
[2] Biotechnical Faculty, University of Bihać, Bihać, Bosnia and Herzegovina

E-mail: dzenita.nutrition@gmail.com

Abstract. One of the first visual representations of dietary recommendations is the food pyramid, which has been used in various forms around the world since the late 20th century. Over time, research on diet and its impact on health has indicated the need for more precise guidelines, leading to the development of new models, including the United States Department of Agriculture (USDA) My Plate and Harvard University's Healthy Eating Plate. The food pyramid actually represents a simple and generally accepted model for a balanced diet that provides guidelines on the necessary representation of certain food groups in the diet and thus ensures the correct ratio of nutrients. The aim of this paper is to analyse the evolution of dietary guidelines, from the first food pyramid in Sweden (1974), then the first American food pyramid (1992), the Harvard University food pyramid (2001) to the Harvard University Healthy Eating Plate concept (2011), and to explore how recommendations have changed in line with new scientific findings. Through a comparative analysis of different dietary models, we explore and highlight the key differences between the food pyramid and the Concept Healthy Plate, emphasizing the benefits of modern guidelines in maintaining health and preventing chronic diseases.

1. Introduction

The concept of a balanced diet has evolved over the decades—from the earliest dietary guidelines to modern models grounded in scientific evidence. Nearly twenty years have passed since the United States Department of Agriculture (USDA) introduced the first Food Guide Pyramid as a visual representation of the main food groups and their recommended daily servings. For over fifteen years, this pyramid served as a foundational and symbolic model in the field of nutrition.

One of the earliest visual tools for communicating nutritional advice was the food pyramid, which, in various forms, was used globally since the late 20th century [10]. However, research on nutrition and its impact on health eventually highlighted the need for more precise guidelines, which led to the development of new models, including the USDA's My Plate and the Harvard Healthy Eating Plate. The Harvard

Healthy Eating Plate, introduced in 2011, was developed as an alternative to the USDA's official guidelines, with the goal of offering clearer and more scientifically grounded dietary recommendations [10]. This model places particular emphasis on food quality, diversity, and moderation, making it one of the most widely accepted tools in modern nutrition education [10]. The aim of this paper is to analyze the evolution of dietary guidelines—from early food pyramids to the Harvard Healthy Eating Plate—and examine how these recommendations have changed in accordance with emerging scientific evidence. Through a comparative analysis of various dietary models, this paper will highlight the key differences between the traditional food pyramid and the Healthy Eating Plate, focusing on the advantages of contemporary dietary guidelines for promoting health and preventing chronic diseases.

2. Historical Development of Food Pyramids

2.1 The First Food Pyramid – Sweden (1974)

In 1974, the first food pyramid was developed in Sweden by the National Board of Health and Welfare as a response to rising food prices and concerns about the population's nutritional status [20]. In the early 1970s, Sweden faced an economic crisis and an increase in the prices of basic foodstuffs, which led to a reduced intake of nutrient-rich foods [2]. To help citizens eat healthily despite economic instability, nutritionist Anna-Britt Agnsäter, who worked for the Swedish Consumer Cooperative Union (Kooperativa Förbundet), proposed a new visual dietary model that was simple to understand and apply [37]. The aim of this model was to provide the population with clear guidelines on a balanced diet based on available and affordable foods.

The Swedish food pyramid was structured in three main tiers, visually representing the priority of different food groups:

1) Base layer: Included inexpensive and filling staple foods such as bread, potatoes, cereals, and pasta. These foods were considered the foundation of the diet as they were readily available and energy-dense.
2) Middle layer: Comprised more expensive but nutritionally essential foods like dairy products, meat, fish, and eggs. These were important for protein and essential micronutrient intake.
3) Top layer: Contained fats, oils, and sweets, which were to be consumed in limited quantities due to their high energy content but lower nutritional value.

The main guideline of this model was for consumers to focus on foods from the base and middle layers while limiting consumption of items from the top layer (Kooperativa Förbundet, 1975). This food pyramid was a simple and accessible tool that helped citizens plan balanced and economical meals, and it served as a foundation for future dietary guidelines. The Swedish food pyramid remained in use for over two decades and served as a foundation for dietary guidelines in many other countries [35]. However, it

was criticized for not distinguishing between healthy and unhealthy nutrient sources and for focusing too much on food quantity rather than quality, which could have contributed to an increased risk of chronic diseases.

2.2 The First American Food Pyramid – USDA (1992)

The first official food pyramid in the United States was introduced in 1992 by the United States Department of Agriculture (USDA), as part of a broader initiative to provide the population with clear guidance on healthy eating [32]. The pyramid was developed based on research into eating habits and nutritional needs, amid growing concerns about rising obesity rates and chronic diseases in the U.S. [21]. Prior to the introduction of the pyramid, the USDA used various visual and educational models to shape American dietary habits. One of the earliest examples was the 'Basic Seven' model from 1943, developed during World War II to ensure adequate nutrition during food rationing and shortages [32]. This model grouped foods into seven categories: vegetables, fruits, dairy, meats and legumes, grains, fats, and butter/margarine. However, the model lacked quantitative recommendations, which limited its practical application.

The USDA Food Guide Pyramid (1992) was divided into four main tiers, each representing a food group with recommended daily servings:

1) Base – Grains (6–11 servings/day): Bread, rice, pasta, and other grain products formed the foundation of the pyramid, promoted as the primary source of energy.
2) Second tier – Vegetables (3–5 servings/day) and Fruits (2–4 servings/day): Highlighted for their essential fiber, vitamins, and minerals.
3) Third tier – Dairy and Protein (2–3 servings/day): Included milk, yogurt, cheese, meat, poultry, fish, eggs, and nuts, valued for their calcium and protein content.
4) Top tier – Fats, Oils, and Sweets: Advised to be consumed sparingly due to their high calorie content and low nutritional value.

Advantages of the 1992 USDA Pyramid

- Simple visual structure: Helped communicate general proportions for different food groups.
  Emphasis on fruits, vegetables, and grains: Promoted fiber-rich foods beneficial to digestive health.
- Promotion of low-fat diets: Reflected prevailing scientific beliefs about fat and cardiovascular risk.
- Broad application: Used in schools, hospitals, and public health campaigns as a foundation for dietary education.

Criticism and Limitations

- Overemphasis on grain intake: Recommended 6–11 servings/day, which modern science links to insulin resistance and type 2 diabetes when refined grains dominate [35].
- Failure to distinguish healthy from unhealthy fats: All fats were grouped together and discouraged, ignoring benefits of unsaturated fats [10].
- Lack of quality focus in protein recommendations: Did not differentiate between lean and processed meats. Despite recommendations, obesity and diabetes rates rose significantly throughout the 1990s [4].
- Critics such as Dr. David Ludwig (Harvard Medical School) emphasized that eliminating healthy fats like olive oil, nuts, and avocado was a critical mistake. Walter Willett (Harvard T.H. Chan School of Public Health) noted the failure to distinguish whole from refined grains. Dr. Robert Lustig (University of California, San Francisco) highlighted how fat-reduced products were often high in sugar, exacerbating metabolic disorders. Authors like Gary Taubes and Nina Teicholz pointed out the influence of industry and weak epidemiological evidence behind USDA recommendations [30, 31].

2.3 *Harvard Healthy Eating Pyramid (2001)*

In 2001, researchers at the Harvard T.H. Chan School of Public Health, led by Professor Walter Willett, introduced the Harvard Healthy Eating Pyramid as a response to the numerous flaws in the 1992 USDA pyramid [35]. The pyramid was based on epidemiological studies, clinical trials, and long-term outcomes associated with different dietary patterns [12].

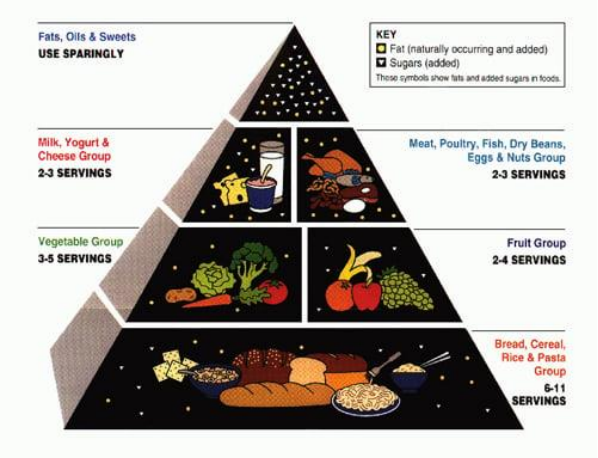

Figure 1. The USDA's original food pyramid, from 1992 to 2005 [39].

Unlike the USDA model, which offered generalized recommendations, the Harvard pyramid emphasized evidence-based components including whole grains, healthy fats, and differentiated protein sources. It was also the first model to incorporate physical activity and weight management as foundational to healthy eating [35].

Key Characteristics of the Harvard Pyramid

1) Emphasis on whole grains: Recommended instead of refined grains due to benefits for heart health, glucose regulation, and metabolic balance [17].
2) Inclusion of healthy fats: Promoted unsaturated fats from olive oil, nuts, and fish, based on studies like PREDIMED that demonstrated a 30% reduction in heart disease risk [6].
3) Differentiated protein sources: Encouraged plant-based proteins (legumes, nuts), moderate fish intake, and limitation of red and processed meats due to links with cardiovascular disease and cancer [22].
4) Limited dairy intake: Advised 1–2 servings/day, or alternative calcium sources, contrasting with USDA's 2–3 servings/day [8].
5) Base layer included physical activity and weight control as lifestyle essentials.

Scientific Validation

- The Nurses' Health Study showed a 20–30% lower risk of coronary heart disease in individuals who followed Harvard's guidelines [35].
- The Health Professionals Follow-up Study linked the model with a lower incidence of type 2 diabetes [28].
- The Adventist Health Study found that diets rich in plant proteins and healthy fats reduced mortality from chronic diseases [7].

Criticism

- The dairy industry opposed limitations on milk consumption, citing its importance for calcium and vitamin D [11].
- Low-fat diet advocates warned that including fats might lead to obesity [3].
- Some critics claimed the model lacked alignment with USDA policies and had limited institutional support [21].

2.4 MyPyramid (2005): Evolution of the USDA Food Pyramid

In 2005, the USDA introduced a redesigned food guidance system called MyPyramid, aiming to address criticisms of the 1992 pyramid and incorporate new scientific findings [32].

MyPyramid featured conceptual and visual updates, including greater focus on personalization and physical activity.

Key Features of MyPyramid

- Personalized diet plans: Introduced tools like MyPyramid Tracker to tailor dietary recommendations to individual needs [14].
- Physical activity emphasis: The icon included a figure climbing stairs to highlight exercise as a key component of health [32].
- Vertical color bands: Replaced horizontal layers with colored stripes representing food groups, suggesting variety without explicit quantity [25].
- Whole grains: Recommended that at least half of all grain consumption come from whole grains [27].
- Healthy fats: Promoted unsaturated fats over saturated fats [19].
- Criticism of MyPyramid
- Ambiguity: The abstract vertical design was confusing and required supplementary explanation [21].
- Lack of clear serving sizes: It did not visually communicate portion guidelines as effectively
  as the 1992 version [18].
- Industry influence: Some critics believed food industry lobbying shaped continued emphasis on dairy and grains [35].

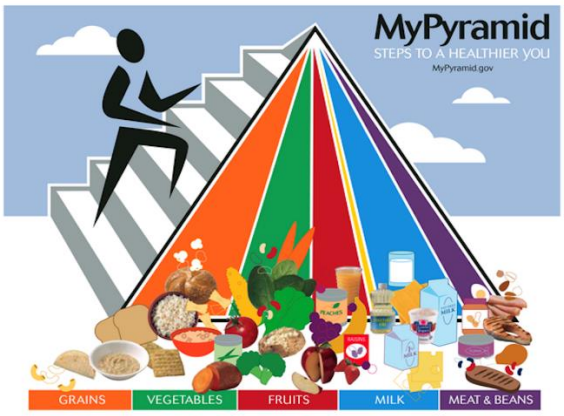

Figure 2. MyPyramid (39)

Despite its updates, MyPyramid failed to reverse obesity trends. By 2008, adult obesity in the U.S. reached 33%, and childhood obesity was at 17% [4].

2.5 MyPlate (2011): Transition to the Plate Model

In 2011, the USDA replaced MyPyramid with MyPlate, a simplified visual model intended to improve public understanding of healthy eating [32]The MyPlate icon displayed a plate divided into four sections representing different food groups.

- 50% of the plate is for fruits and vegetables, emphasizing variety and freshness.

- 25% is reserved for grains, with a preference for whole grains.
- 25% for proteins, including both plant and animal sources.

A separate circle beside the plate represents dairy, commonly interpreted as a glass of milk.

Advantages of MyPlate

- Simplicity: Removed complexity of previous pyramids, offering a clear and intuitive layout [26].
- Scientific alignment: Encouraged balanced diets with increased fruits, vegetables, and whole grains [16].
- Visual effectiveness: Helped consumers make better food choices by focusing on food groups and portion balance.

Criticism of MyPlate

- Fat exclusion: Did not distinguish between healthy and unhealthy fats, unlike the Harvard Healthy Eating Plate [19].
- Dairy emphasis: Inclusion of milk as a default side was debated due to limited evidence of its necessity [9].
- Industry influence: Critics noted continued bias toward food groups promoted by large agricultural sectors [21].

Although MyPlate was widely adopted in educational campaigns, early data showed little improvement in obesity rates [4].

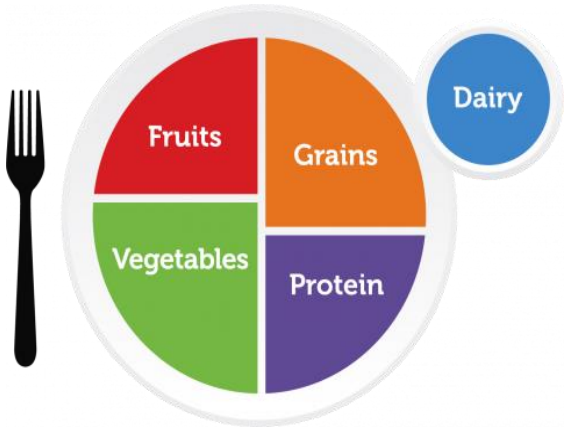

Figure 3. MyPlate [38]

2.6 Harvard Healthy Eating Plate (2011)

In 2011, researchers at the Harvard T.H. Chan School of Public Health and Harvard Medical School introduced the Healthy Eating Plate as a scientifically advanced alternative to USDA's MyPlate [10]. This model emphasized food quality, diversity, and disease prevention, distinguishing it with clearer, evidence-based guidelines.

Key Features of the Healthy Eating Plate

- Half the plate: Fruits and vegetables, with a focus on variety. Potatoes and processed juices were discouraged due to their high glycemic index [19].
- One-quarter: Whole grains such as quinoa, brown rice, and whole wheat bread. Refined grains like white rice and white bread were discouraged due to negative metabolic effects [35]
- One-quarter: Healthy proteins including legumes, nuts, tofu, and fish. Red meat was advised in moderation, and processed meats were to be avoided [24].
- Healthy fats: Emphasized unsaturated fats from olive oil, nuts, and fish while advising against trans fats and highly processed oils [12].
- Water: Recommended as the primary beverage. Milk was not considered essential [10].
- Physical activity: Included as an integral part of the model, reinforcing its role in holistic health [5].

Advantages of the Healthy Eating Plate

- Based on scientific evidence: Grounded in decades of epidemiological and clinical research [35].
- Distinguishes food quality: Clearly separates whole vs. refined grains, healthy vs. unhealthy fats, and diverse protein sources.
- Disease prevention: Associated with lower risk of cardiovascular disease, obesity, and type 2 diabetes [24].

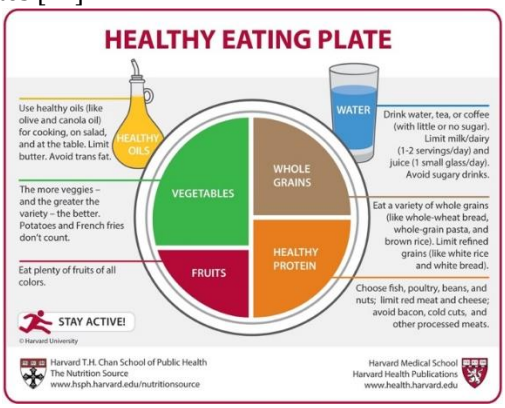

Figure 4. Healthy Eating Plate [10]

Criticism

- USDA misalignment: Critics argued the model conflicted with government policy and agricultural interests[21].
- Lack of government endorsement: Despite its scientific validity, the model was not officially adopted in public health campaigns [9].

Scientific Evidence

- The Nurses' Health Study and Health Professionals Follow-up Study showed significant reductions in chronic disease risk when following Healthy Eating Plate principles [29].
- A 2016 Harvard study linked the model with lower BMI, LDL cholesterol, and improved insulin sensitivity [15] study projected a 20% reduction in global mortality if more people adhered to such guidelines[1].
- European studies connected the model to reduced symptoms of depression and anxiety, attributed to increased intake of omega-3s, fiber, and antioxidants [13]. A 2022 study found a 35% lower risk of type 2 diabetes among individuals adhering to the model compared to Western diets [36].

3. Conclusion

The historical evolution of dietary guidelines, from Sweden's initial pyramid in the 1970s to the USDA's MyPlate and Harvard's Healthy Eating Plate, reflects substantial advancements in the understanding of nutrition and public health.

Early models, though innovative, were limited in scope and often influenced by industry or outdated science. Modern frameworks such as the Harvard Healthy Eating Plate emphasize nutrient quality, plant-based diversity, and lifestyle integration, offering a more holistic approach to chronic disease prevention. These developments underscore the need for dietary guidance rooted in independent research, public health priorities, and adaptability to new scientific discoveries.

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The Use of SMART Indicators in Environmental Protection Project Management

Halid Makić[1], Amela Čolić[2], Elvedin Miljković[3] and Ikbala Makić[4]

[1] Biotechnical faculty University of Bihać, Bihać, B&H
[2] Faculty of law University of Bihać, Bihać, B&H

E-mail: halid.makic@unbi.ba

Abstract. In order to manage environmental protection projects efficiently, it is necessary to define precise and effective methods of planning, monitoring, and evaluating objectives. In this context, SMART indicators represent a key tool for defining the success of project activities. The acronym SMART stands for the criteria that indicators must meet: Specific, Measurable, Achievable, Relevant, and Time-bound. This paper analyzes the application of SMART indicators in various fields of environmental protection, including: air quality management, waste management, energy efficiency, sustainable water management, biodiversity conservation, and soil protection. The paper emphasizes the importance of applying the SMART approach in ecological projects as it enables transparency, objectivity, and better resource management. It also highlights the need for systematic monitoring and evaluation of projects to ensure their long-term sustainability and alignment with national and international environmental protection policies.Through a review of literature and case studies, this paper contributes to the understanding of the role of SMART indicators in environmental management and provides guidelines for their effective implementation in future environmental protection projects.

1. The role of indicators in project management

In the context of project management, indicators are key tools that enable the measurement of progress, efficiency, effectiveness, relevance, and impact of a project in relation to its objectives. Regarding project success, there are key performance indicators (KPIs) that must be included in the project management process. KPIs are organizationally grounded and have quantitative metric value [1]. In every project, they must be presented in the form of a management dashboard and adopted by project managers. Without clearly defined and measurable indicators, it is difficult to track whether the project is moving in the right direction, whether desired results are being achieved, and how to optimize activities to achieve better outcomes.

Indicators are traces, signs, or markers that measure one aspect of a program and show how close the program is to its intended path and results. Indicators are defined as realistic and measurable criteria of project progress. Therefore, it is essential to define them during the preparation phase of the project application, i.e., before the project starts, and to enable monitoring or evaluation of whether the implementation of the project meets the defined goals.

In project planning, indicators form a link between theory and practice. An indicator is a tool that helps implementers quantify whether a project is progressing and how much the project activities contribute to achieving the objectives. Indicators usually describe observable changes or events related to the project intervention. They provide evidence that something has happened—whether a result was achieved, an immediate effect occurred, or a long-term change was observed.

In the context of defining the terms "project" and "program", it is important to distinguish between program and project indicators. A project is limited in time, budget, and scope, and has clearly defined objectives, activities, and expected results, while a program is a set of related projects that contribute to achieving a broader strategic goal—often long-term and covering multiple sectors or topics.

Indicators used to measure progress, effects, and results at the level of an individual project are called project indicators. They focus on the specific, operational objectives of the project. They are measured during implementation and immediately after project completion and relate to outputs (results of activities) and outcomes (short-term impacts).

In the context of environmental project management, e.g., if the goal of a project is the introduction of digital tools for environmental management, then an indicator could be the number of users registered on the e-platform for reporting environmental incidents. Or, if the goal of the project is to improve efficient resource use, then an indicator could be the percentage reduction in water consumption in pilot facilities after the implementation of savings measures.

Program indicators are indicators used to monitor and assess the broader program impact and strategic contribution, often across multiple related projects. They are typically focused on long-term goals and strategic outcomes and may involve multiple sectors and data sources. These indicators are used for program monitoring and evaluation at the national, regional, or international level.

For example, if the program goal of a project is climate change mitigation (SDG 13 – Climate Action), then program indicators could be CO_2 eq emissions by sector (transport, industry, energy), the share of renewable energy in final consumption, or the number of local climate action plans developed. If the program goal is biodiversity and ecosystem conservation (SDG 15 – Life on Land), then program indicators could be the area of protected zones (% of territory), the number of endangered species under active protection measures, or the area of restored degraded land (in hectares).

1.1 The roles of indicators in project management

Indicators play a key role in planning and analyzing the logical framework. There are many different types of indicators: some are more common than others, some better than others, some easier to collect than others, and some more widely recognized than others. The formulation of indicators has become a major area of the development process and project implementation, as it indicates whether the project has met expected goals and whether project activities have resulted in quality solutions contributing to achieving the project's objectives.

Within the logical matrix, it is important to define objectively verifiable indicators. Objectively Verifiable Indicators (OVI) are standards by which change can be measured. They set goals in terms of Quantity, Quality, and Time (QQT). Indicators must be specific, usable, measurable, sensitive, cost-effective, and available [6].

1.1.1 Indicators in project management can serve multiple roles: Monitoring progress

Indicators allow for continuous monitoring of activities throughout the project duration. Monitoring can reveal whether activities are being carried out as planned. Most authors have defined "performance measurement." According to Neely et al. (2005), performance measurement is defined as the process of quantifying the efficiency and effectiveness of action [7]. According to Choong (2014), performance measurement relates to improving performance goals, detecting deviations, and taking corrective action if goals are not met [8]. Morris and Pinto (2010) defined "project success" as a compromise between several dimensions, especially what is done (scope and quality) in relation to the resources (time and cost) used to do the work [9].

1.2 Evaluation of results and impact

At the end of a project (or in evaluation phases), indicators serve to assess achievements. Results are compared with the baseline and target values. The use of performance-oriented indicators is relatively new and has emerged only in recent decades. A significant number of authors consider their use a key factor in project management. Project delivery and project management require different sets of metrics to track their successful progress. Initially, these indicators relied on the characteristics of a specific project, but later became generalized, as the process is often similar across projects regardless of their nature. In the literature review on this topic, most references are focused on specific aspects of project management such as earned value analysis, risks, project evaluation, or maturity models [10].

Well-chosen indicators are significantly helpful in decision-making and risk management. Specifically, well-defined indicators help project managers make informed decisions, adjust plans, and identify risks or weaknesses in time. They are also important in communication with all project stakeholders, as indicators provide a transparent and standardized way of reporting — especially important for international partners, donors, governments, and communities. Clearly defined indicators enable

responsibility for achieving results to be shared among the teams and institutions involved in implementation [11].

1.3 Types of Indicators in Project Management Direct and indirect indicators

Project management in the field of environmental protection requires defining indicators to measure the success of implementing activities, achieving goals, and overall contribution to sustainable development. These indicators can be divided into direct and indirect.

Direct indicators are used for objectives related to directly observable change. These are usually at the level of results and activities in the logical framework. A direct indicator is simply a more precise, comprehensive, and operational representation of the corresponding goal. Indirect or proxy indicators can be used instead of or alongside direct indicators. Below are commonly used direct and indirect indicators in environmental project management [12].

Direct indicators in environmental project management refer to concrete, measurable effects of project activities on the environment, such as:

- Reduction of CO_2 emissions (in tons per year)
- Increase in the amount of recycled waste (%)
- Increase in the number of protected natural areas (in hectares)
- Improvement in the quality of air/water/soil (e.g., reduction in NO_2, BOD, heavy metals, etc.)
- Number of remediation measures implemented at polluted sites
- Number of installed green technologies (e.g., solar panels, wastewater treatment plants, etc.)
- Increase in energy efficiency of buildings (kWh/m^2)
- Biological indicators (e.g., increase in biodiversity index)

Indirect indicators or indicators of societal and behavioral impact refer to changes in behavior, knowledge, policies, or perception resulting from the project but not directly linked to physical changes in the environment, such as:

- Increased public awareness of environmental protection (measured by surveys)
- Number of educated individuals (citizens, students, officials, etc.)
- Changes in legislation or local policies
- Increased public participation in decision-making (e.g., number of public hearings, consultations)
- Increased number of partnerships between institutions, NGOs, and local communities
- Media visibility of the project (number of media articles, online views, website visits)
- Use of developed tools/platforms (e.g., digital app for reporting environmental issues)

- Introduction of environmental criteria in procurement, planning, and construction
- Qualitative and Quantitative Indicators

The maximum of quality, quantity, time (QQT) for defining indicators generally works well. However, its rigid application may result in the exclusion or undervaluation of performance and changes that are difficult to quantify. Because change is often hard to quantify or qualitative data analysis is not straightforward, it is often ignored. Instead, special effort and attention should be dedicated to designing qualitative indicators. A balance of indicators is needed — some focused on quantitative, others on qualitative aspects. In this context, it is practical to apply the QQT matrix. The QQT matrix is a tool that allows each project activity to be precisely defined in three key dimensions [13]:

A) Quality (Q – Quality): The standard the activity or result must meet (e.g., expertise, compliance with regulations, user satisfaction)

B) Quantity (Q – Quantity): Measurable volume of activity or result (number of trainings, participants, samples, publications, etc.)

C) Time (T – Time): The time frame in which the activity must be realized (deadlines, frequency, duration)

2. SMART indicators – concept and application

SMART indicators are specifically defined indicators that allow for clear and measurable monitoring of project goals. The acronym SMART stands for five key characteristics.

Table 1. SMART indicators

Letter	Leaning (English)	Translation	Description
S	Specific	Specific	Clearly defined: Who? What? Where? How?
M	Measurable	Measurable	Quantitatively or qualitatively measurable
A	Achievable	Achievable	Realistic and attainable with available resources
R	Relevant	Relevant	Aligned with the project's goals and priorities
T	Time-bound	Time-bound	Has a clear time frame

When the goal or intended outcome of a project program is immediate, short-term, or medium-term, it can often be directly measured for success. On the other hand, long-term outcomes are often harder to measure and are subject to a greater influence of

external factors beyond the control of project management. For this reason, the concept of “indicators” of success is necessary. An “indicator” is a quantitative measure that provides some degree of evidence that a goal is being achieved. It is what people would “see, hear, feel, or do” to confirm the project goal is being realized [14]. (Certificate Program in Strategic Management and Performance Systems, George Washington University, 2019) Indicators that are SMART—Specific, Measurable, Achievable, Relevant, and Time-bound—ensure the collection of reliable evidence on how much or how well objectives are being met [15]. SMART indicators help clearly define the quantity and quality of expected changes and ensure that they are measurable (i.e., reportable, countable, or observable); that the goals are time-bound and achievable within the project’s scope and scale; and that the resulting data will be relevant and useful for decision-making.

Example of a SMART indicator in environmental protection, i.e., applying SMART criteria when considering potential indicators related to the goal of “households implementing best sustainable energy practices” [16].

SMART Indicator (at the OUTCOME level): Indicator: "By the end of 2026, at least 60% of households in the target region have reduced their annual electricity consumption by 15% through the use of energy-efficient appliances and thermal insulation."

Table 2. SMART Indicator (at the OUTCOME level).

SMART Criterion	Explanation	SMART Criterion	Explanation
Specific	Clearly defined goal: reducing household energy consumption	Specific	Clearly defined goal: reducing household energy consumption
Measurable	Percentage of households (60%) and specific reduction level (15%)	Measurable	Percentage of households (60%) and specific reduction level (15%)
Achievable	Based on prior data and available support (e.g., subsidies)	Achievable	Based on prior data and available support (e.g., subsidies)
Relevant	Directly contributes to sustainable energy use and emission reduction	Relevant	Directly contributes to sustainable energy use and emission reduction

Time-bound	Deadline defined by the end of 2026	Time-bound	Deadline defined by the end of 2026

SMART Indicator (at the OUTPUT level):
Indicator: "By the end of 2025, at least 2,000 households have completed energy efficiency training, and 1,000 have received subsidized LED bulbs and insulation materials."

Table 3. SMART Indicator (at the OUTPUT level).

SMART Criterion	Explanation
Specific	Training and equipment distribution for sustainable energy
Measurable	Number of households (2,000 and 1,000)
Achievable	Achievable within the planned period and allocated budget
Relevant	Activities that enable behavioral change (outcome level)
Time-bound	Activities completed by the end of 2025

3. Conclusion

Through clearly defined, measurable, achievable, relevant, and time-bound indicators, it is possible to accurately plan, monitor, and evaluate results both at the level of specific activities (output) and long-term changes (outcome and impact).

In the context of growing environmental challenges and the need for responsible use of public and international funds, SMART indicators enable better decision-making, timely adjustments during implementation, and demonstrate the project's impact to donors and the community.

By combining quantitative and qualitative indicators and ensuring the availability of reliable verification sources, projects can genuinely contribute to environmental protection and sustainable development.

Therefore, the integration of SMART indicators already in the design phase and in the project’s logical framework is not just a technical tool, but a strategic approach to responsible, systematic, and results-oriented environmental project management.

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The impact of UV radiation on the antioxidant activity of meadow honey

Dženaida Ostrvica[1], Alma Muminagić[2], Mejra Bektašević[1], Sanja Mihić [2], Anita Vuković [1] and Amira Mulalić[1]

[1] Biotechnical Faculty, University Bihać, Bihać, Bosnia and Herzegovina
[2] Gymnasium Bihać, Bihać, Bosnia and Herzegovina

E-mail: dzenaida995@gmail.com

Abstract. Honey is a concentrated aqueous solution of inverted sugars, mainly glucose and fructose. It contains a variety of amino and organic acids, vitamins, minerals and antioxidants. Honey is rich in flavonoids, phenolic acids and carotenoids. The antioxidant properties of honey are mostly due to its organic acids, and phenolic components, mainly flavonoids. Wide variations in composition of different types of honey are the result of the diversity of bee species, as well as differences in weather conditions and botanical sources at the collection sites. As part of the "Cubes in Space" project, which was implemented with support of NASA USA, samples of meadow honey, collected in BiH, were launched to an altitude of 40 000 m above the Earth, where they were exposed to space, honey was analysed for total phenol content and antioxidant activity using two methods; the DPPH free radical scavenging method, and the FRAP method, which tests the reducing ability of the tested samples. The obtained results were compared with the results for the same samples of meadow honey stored on Earth, at room temperature and protected from sunlight.

Keywords: Honey, Cubes, Space, Antioxidants, Phenolic

1. Introduction

Honey is one of the most valuable natural bee products (lat. Apis mellifera), which bees collect from flower nectar or plant secretions, and then turn it into a natural product called honey [1]. It is well known as a source of enzymatic and non-enzymatic antioxidants such as catalase, glucose oxidase, flavonoids, phenols, proteins, vitamins and Maillard reaction products. In addition, its composition is dominated by carbohydrates, the most abundant of which are glucose and fructose (85 - 95 %) [2].

The main antioxidant compounds in honey are polyphenols in the form of phenolic acids and their derivatives and flavonoids [3, 4]. Among the phenolic acids, coumarin, gallic, ellagic, caffeic and ferulic acids and their esters can be distinguished [5]. The main role of antioxidant compounds present in honey is the neutralization of free radicals, which is especially played by polyphenols with multiple effects in the prevention and treatment of many diseases. Polyphenols can also stimulate the secretion of antioxidant

enzymes such as catalase, glutathione peroxidase, glutathione reductase and superoxide dismutase [6].

Thanks to its biologically active components, honey has antibacterial, anti-inflammatory, antihypertensive, hepatoprotective and hypoglycemic effects [7, 8, 9, 10, 11, 12, 13]. However, the chemical and physical properties of honey as well as its antioxidant properties depend on its botanical origin, climatic conditions and geographical origin, i.e. the area where bees collect pollen and nectar [14, 15]. Thus, darker types of honey have a higher total content of phenolic compounds, i.e. a higher proportion of phenolic acids, and thus their antioxidant activity is higher. Therefore, the color of honey is one of the indicators of antioxidant activity [16]. Thanks to its unique chemical composition, honey is a complex food product that has been used for centuries as a source of food, but also as a medicine, and no two samples of honey are identical [17, 18].

From the time honey is produced until it is consumed, it is inevitably exposed to environmental influences such as storage methods, temperature, sunlight, etc. Exposing food to sunlight increases the amount of ultraviolet (UV) radiation, but there are still not enough studies on the impact of natural ultraviolet (UV) radiation on the antioxidant properties of honey [19].

The main source of ultraviolet (UV) radiation is the Sun, and the intensity of radiation depends on latitude, altitude, season and time of day. With an increase in altitude of 1000 m, UV radiation increases by 6-8%, because the layer of the atmosphere that filters UV radiation is thinner. For every additional 1000 meters in altitude, the radiation level increases by 10 to 12% [20]. Wavelengths of electromagnetic UV radiation range from 10 to 400 nm. UV radiation has the ability to reach the surface of the Earth and in relation to their influence on biological processes, they can be divided into three groups: UV-A (315-400 nm), UV-B (280-315 nm) and UV-C (<280 nm). UV-C radiation has a wavelength with high energy, but it has no possibility of reaching the Earth's surface, because it is absorbed or completely filtered in part of the ozone layer. In contrast, UV-A and UV-B radiation have the ability to reach the Earth's surface [21]. In addition to the fact that ultraviolet (UV) radiation is found in nature, it can be produced artificially and as such has many applications in the production and analysis of food [22].

Considering the benefits from the health aspect and consumer demand for high-quality bee products, preserving and improving the antioxidant properties of honey during handling and storage are of great importance [23]. Therefore, the aim of this study is to determine the antioxidant capacity of meadow honey from Bosnia and Herzegovina after its exposure to ultraviolet (UV) radiation at 40,000 m above the Earth. The importance of the study is reflected in the examination of the quality and the very sustainability of the chemical-physical properties of honey against changing environmental conditions.

Figure 1. Participants of the project supported by NASA

For foods containing polyphenols that are exposed to space radiation, it is difficult to estimate the actual rate of their antioxidant capacity, as well as the absorption of nutrients during consumption in space [24, 25, 26]. For more than six decades, humans have been exploring space, as well as the temperature fluctuations, low gravity, and short-wave solar UV radiation that characterize the space environment, which is illuminated by various types of radiation [25, 27, 28].

Figure 2. The sample launch station

Space travel carries with it unique and numerous hazards, such as changing gravity, isolation, confinement, and radiation. Each of these carries with it potential consequences.

Figure 3. Samples stored in the spacecraft capsule

Therefore, nutrients are of great importance for space flights. Polyphenols have attracted special attention for space travel, as the most widespread group of phytochemicals with numerous health benefits, especially in space [29, 30].

2. Material and methods

2.1 Samples

In this research, samples of meadow honey from the area of Bosanska Krupa, Bosnia and Herzegovina, stored on Earth and launched to an altitude above 40,000 m into the space environment were analysed.

Figure 4. Samples of meadow honey solutions prepared for analysis

Meadow honey samples were stored in a glass container in a dark place at a temperature of +4°C until analysis, unlike the samples that were launched into space.

2.2 Chemicals and Instruments

The used analytical grade chemicals in this work were: 5,5-Dithiobis(2-nitrobenzoic acid) DTNB, 2,4,6-Tris(2-pyridyl)-s-triazine TPTZ, bovine serum albumine (BSA), Glucose, Fructose, Sucrose, Maltose (Sigma-Aldrich, GmbH, Steinheim, Germany); BHA (Butylated hydroxyanisol), BHT (Butylated hydroxytoluene), Sodium carbonate, Sodium hidroxide (Acros Organics, USA); Gallic acid (Carl Roth, GmbH); Folin-Ciocalteu's reagent (Darmstadt, Germany); Ethanol 96 %, HCl, $FeCl_3$ x $6H_2O$, $FeSO_4$ x $7H_2O$, $K_4Fe(CN)_6$ x $3H_2O$, $Zn(CH_3COO)_2$ x $2H_2O$ (Kemika, Zagreb). The spectrophotometric measurements were performed on a photoLab 6600 UV-VIS spectrophotometer.

2.3 Analysis of total phenol content

The total phenol content of meadow honey samples was determined using the Folin-Ciocalte (FC) method, and the results were presented in mg gallic acid/g honey [31]. To determine the total phenol content, the tested honey samples were prepared as follows: 5 g of honey, previously weighed, was dissolved in 20 mL of water using an ultrasonic bath. Then, the dissolved samples were transferred to a 100 mL volumetric flask and made up to the mark with distilled water. The analysis of the total phenol content was performed according to the method described in Bektašević and Politeo (2023) [32]. The concentration of total phenols was calculated based on the calibration curve of gallic acid (Figure 5). The results obtained were expressed in mg gallic acid per g of honey (mg GAE/g honey).

2.4 DPPH method

According to the method of Brand Williams et al [33], the antiradical activity of the tested honey samples was determined with the application of certain modifications from Beretta et al. [35] with the use of 1900 µL of DPPH reagent (in 96 % ethanol a DPPH radical solution of 130 µM was added) and 800 µL of acetate buffer (100 M, pH 5.5), and 300 µL of honey sample solution (10 %). The sugar analogue was the control sample. Absolute alcohol was used to zero the apparatus and the absorbance of the DPPH reagent was also measured. Acetate buffer was added to each sample instead of DPPH for blank tests. After that, the prepared samples were left in the dark for 60 minutes, and then the absorbance was read at 517 nm. Based on the use of the formula: % inhibition = [(A0 – Sample) / A0] x 100, the radical scavenging ability of the tested samples was calculated, where A0 represents the absorbance of the ethanolic DPPH solution measured initially at 517 nm and sample – the absorbance of the sample measured after 60 minutes. The obtained analysis results are expressed as percentages of DPPH radical inhibition.

2.5 FRAP method

The antioxidant capacity of honey was determined by the FRAP method [34]. The principle of performing this method is based on the reduction of the iron complex 2,4,6-tris-pyridyl-s-triazine (Fe3+ - TPTZ) into a colored form (Fe2+ - TPTZ) with the presence of antioxidants. The FRAP reagent contained 2.5 ml of a solution of 2,4,6-tris-pyridyl-s-triazine (TPTZ) in 40 mM HCl, 25 ml of 0.3 M acetate buffer (300 M, pH 3.6) and 2.5 ml of 20 mM FeCl3 x 6H2O. The FRAP reagent was prepared immediately before use and during the analysis the temperature of the water bath was maintained at 37°C. 1.8 ml of FRAP reagent was mixed with 200 µL of the sample, and the absorbance of the reaction mixture was measured at 593 nm spectrophotometrically. A standard aqueous solution of FeSO4 x 7H2O (0.1 to 1 M) was used to calculate the FRAP value, and the results obtained were expressed as the FRAP value in µM Fe(II)/g honey.

2.6 Statistical data analysis

The results of the analyzed samples are presented as mean value ± standard deviation. One-way analysis of variance (ANOVA) and multiple comparisons (Duncan's Post Hoc Test) were used to assess the significant difference in data at the $p<0.05$ significance level. Statistics were implemented using Microsoft Office 2014 and the demo version of the statistical package MS Office XLSTAT-Pro 2014 [35].

3. Results and discussion

The results of antioxidant activity and total phenol content in samples of meadow honey stored on Earth and sent into space are presented in Table 1. Meadow honey samples were analyzed with the aim of assessing their antioxidant activity and finding a correlation between total phenol content and antioxidant activity during different

storage conditions and exposure to conditions at 40,000 m above Earth. The results obtained (Table 1) showed that the analyzed meadow honey samples stored on Earth and samples sent into space did not have significant differences and deviations in total phenol content, and that all analyzed samples were antioxidant active. The total phenol content in honey samples ranged between 0.79 ± 0.02 mg gallic acid/g meadow honey stored on Earth, 0.75 ± 0.08 mg gallic acid/g meadow honey sent into space.
The high content of phenols in the analyzed samples of honey from the area of the Una-Sana Canton points to the good quality of meadow honey in terms of the content of bioactive components.

In order to be able to determine the total phenol content, a calibration curve of gallic acid was determined in samples of meadow honey stored on Earth and sent into space. The picture shows the gallic acid calibration curve, whose equation reads:

$y = 0.0017x + 0,0239$; $R^2=0.9926$,

where:
y – absorbance at 750 nm,
x – concentration of gallic acid (mg/mL).

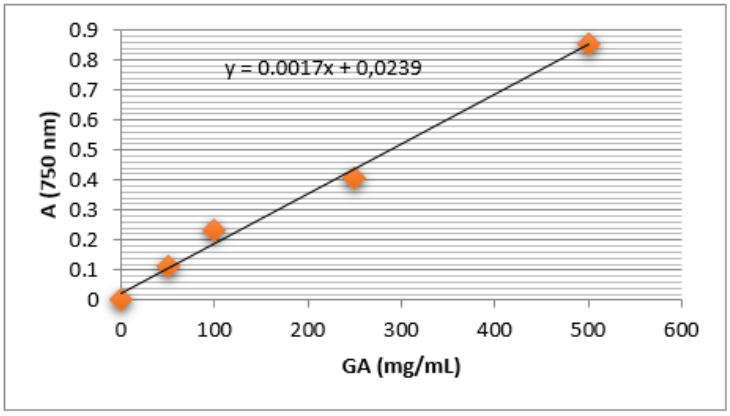

Figure 5. Gallic acid calibration curve

Table 1. Total phenolic content and antioxidant activity in meadow honey samples

Analysis	Sample	
	H Earth	H Space
Total phenol content (mg GAE/g honey)	0.79 ± 0.02	0.75 ± 0.08
FRAP (μM Fe(II)/g honey)	3.68 ± 0.41	4.02 ± 0.14
DPPH (% of inhibition for 5% solution)	16.56 ± 1.41	16.62 ± 1.57

The presented results of meadow honey in terms of the content of total phenols are in accordance with the results obtained by Toromanović et al. (2024) and higher compared to the research on honey by Oraščanin et al. (2024) and Bertoncelja et al. (2007) [36, 37, 38]. Al Mamary et al. [36] in their research stated that the determination of the total phenol content is one of the very good parameters for assessing the quality of honey, as well as its possible therapeutic potential. Certain variations in the phenol content of honey samples compared to the research on honey by Oraščanin et al. (2024) and Bertoncelja et al. [37,38] may be a consequence of the different water content in the samples, as well as the botanical and geographical origin of the honey.

FRAP and DPPH methods were chosen to measure antioxidant activity due to their simplicity, precision and accuracy. The DPPH test is used very often to measure antioxidant activity because its direct connection with the total content of phenols and flavonoids [39] has been proven. The presented values of the analyzed samples of meadow honey (table 1) from the area of the Una-Sana Canton tested by the DPPH method showed that there is no significant deviation of inhibition between the samples stored on Earth and those sent into space. The obtained values are approximately the same, with the fact that the inhibition capacity slightly increased in the case of meadow honey sent into space. The results of the analyzed samples for meadow honey stored on Earth ranged between 16.56 - 1.41 % and 16.62 - 1.57 % for the samples of meadow honey sent into space. The obtained results of DPPH measurement for meadow honey originating from BiH (Unsko-Sana canton, Bosanska Krupa area) are in accordance with the results for different types of honey from BiH and Slovenia [37, 38].

The FRAP method for determining antioxidants is used to assess the reducing and antioxidant capacity of honey. Antioxidant activity is estimated based on the antioxidants present and the ability to reduce Fe (III) to Fe (II). The results obtained by the FRAP method indicate a slightly reduced ability to reduce the sample of meadow honey stored in space. The obtained research values are shown in table 1 and are expressed in μM Fe(II)/g honey. The reduction potential for the sample of meadow honey stored on Earth ranged between 3.68 ± 0.41, and for the sample of honey sent into space, a slightly higher FRAP of 4.02 ± 0.14 μM Fe(II)/g honey was recorded. As can be seen, the values obtained for honey from the Una-Sana Canton were without significant changes after exposing meadow honey samples to different storage conditions, and the results obtained using the FRAP method indicate a lower value compared to the results obtained using the same method for honey from BiH, Slovenia, and Croatia [37, 38, 40]. Compounds that can contribute to increased antioxidant activity in honey include the presence of ascorbic acid, carotenoids, polyphenolic compounds and tocopherols.

The statistical analysis shows a positive correlation between DPPH and total phenol content (TFC Earth r= 0.9834; TFC Space r= 1, $p<0.05$), as well as a positive correlation between FRAP and total phenol content (TFC Earth r=0.9999, TFC Space r=

0.8622, $p<0.05$). There was no statistically significant difference in terms of total phenol content, and antioxidant activity between samples from Earth and space.

4. Conclusions

The purpose of the work was to conduct a study of meadow honey samples from the Una-Sana Canton exposed to different conditions (Earth and Space), and to determine the total phenol content and antioxidant activity using the DPPH and FRAP methods. After obtaining the results of this research and analyzing the samples, the following conclusions can be drawn. Based on the obtained results of the total phenol content, there are no significant differences between the parameters of honey samples stored on Earth and sent into space. The highest content of total phenols was found in the meadow honey sample stored on Earth. The results of determining the antioxidant activity using the FRAP method indicate a slight decrease in the reduction ability of the meadow honey sample sent into space, and by testing the samples using the DPPH method, the values obtained showed a slight increase in the inhibition ability compared to the meadow honey samples stored on Earth. According to the obtained results of this research, it can be concluded that the meadow honey originating from the Una-Sana Canton is of exceptionally good quality. The composition of honey and its polyphenol content, as well as its antioxidant activity, depend on the region, soil, climate, pollution level, storage method and many other factors. Since polyphenols are present in all plants, they are also found in honey. The good quality of meadow honey originating from the Una-Sana Canton is supported by its geographical location, which is extremely rich in diverse flora.

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The influence of temperature on the development and sporulation of the tested Alternaria spp. Isolates

Mehira Perviz[1]and Osman Perviz[2]

[1] Agricultural Institute of Una-Sana Canton, Bihać, Bosna I Hercegovina
[2] Faculty of Biotechnology, University of Bihać, Bosna I Hercegovina

E-mail: mehirakapic@gmail.com

Abstract. Six selected Alternaria spp. isolates were used in these studies, namely: A:1) FM-15; 2) BM-2; 3) CLA-108 control isolate for A. dauci; B: 4) Mr-114; 5) IM-14, and 6) Aa-82 control isolate for A. alternata. The influence of different temperatures on the growth and sporulation of selected Alternaria spp. isolates was tested at six different temperatures, namely: 3, 12, 20, 23, 27 and 33 °C. To test the influence of different temperatures on colony growth and sporulation, the tested isolates were grown on a potato-dextrose agar for 10 days, and radial growth, average daily growth and sporulation were tested for all isolates. The growth rate was determined after seeding by measuring the colony diameter after 3, 5, 7 and 10 days in five replicates, while the intensity of sporulation was expressed as the number of conidia per 1 cm2 of colony. The tested isolates of group B had the highest radial growth at a temperature of 27 °C, then at a temperature of 23 °C, and at temperatures of 33 °C and 20 °C, while the radial growth was significantly lower at a temperature of 12 °C and the lowest at a temperature of 3 °C. In contrast, the tested isolates of group A had the highest radial growth at a temperature of 27 °C, then at temperatures of 23 °C and 20 °C, while a significantly lower radial growth was recorded at temperatures of 33 and 12 °C, and the lowest at a temperature of 3 °C. Sporulation of individual group B isolates (Mr-114, IM-14, Aa-82) at all tested temperatures varied from weak to very abundant sporulation, while sporulation of individual group A isolates (CLA-108, BM-2, FM-15) varied from no sporulation to very weak sporulation.

1. Introduction

Fungi belonging to the genus *Alternaria* cause a complex of diseases on carrots and greater yield losses than any other single pathogen. Changes in cultivation methods and the introduction of modern intensive carrot production have additionally influenced the more intense occurrence of existing pathogens, especially those with a wide range of hosts, such as species of the *Alternaria* genus. As distinct cosmopolitans with an exceptional ability to adapt to different environmental conditions, they are present in both humid and semiarid regions, where they can infect numerous cultivated plants,

attacking leaves, stems, flowers and fruits. The given studies are in accordance with the range of minimum, optimal and maximum temperatures for cultivation in our climate.

Analysis of the influence of temperature on the growth and sporulation of six selected *Alternaria spp.* isolates was done by sowing them in Petri dishes on a potato-dextrose agar, which, after sowing, were incubated in the dark at the following temperatures: 3 °C, 12 °C, 20 °C, 23 °C, 27 °C and 33 °C.

Colony growth during exposure to different temperatures was monitored daily by measuring the diameter of the colony over a period of 10 days. The influence of different temperatures on the growth of colonies of selected *Alternaria spp.* isolates, i.e. six selected *Alternaria spp*. isolates, namely: 1) FM-15 isolate from Bosnia and Herzegovina; 2) BM-2 isolate from Serbia; 3) CLA-108 control isolate for *A. dauci*; 4) Mr-114 isolate from Bosnia and Herzegovina; 5) IM-14 isolate from Serbia, and 6) Aa-82 control isolate for *A. alternata* was calculated as the average daily increase, while the intensity of sporulation was expressed through the number of conidia per 1 cm^2 of the colony. The experiment was set up in five repetitions.

2. Material and working methods

2.1. Parasite isolation

Isolation of fungi of the *Alternaria* genus from the collected samples of diseased carrot plants was performed according to the standard phytopathological procedure [2], by aseptically placing small fragments, taken from the junction of healthy and diseased tissue of diseased carrot plant parts, on a potato-dextrose agar in a Petri dish.

After five days of development in a thermostat, at a temperature of 25 °C, fungal colonies developed around the sown fragments, from the edges of which parts of the mycelium were carefully cut, together with a thin layer of agar, which were then transferred to test tubes with a slanted potato-dextrose agar. In this way, a large number of pure cultures of *Alternaria spp*. were obtained.

The monospore culture method was used to purify the obtained *Alternaria spp*. isolates. According to this method, in Petri dishes with a developed *Alternaria spp*. colony on the potato-dextrose agar, 10 ml of sterile water was added, after which the mycelium with conidia was removed by gentle rubbing with a glass rod in order to separate them from the agar. After that, with the further addition of sterile water, dilutions of the resulting conidia suspension of 10^{-1} and 10^{-2} were prepared, from which 0.1 ml of the suspension was seeded in a Petri dish on a water and agar substrate according to the method of [2]. Petri dishes sown in this way were incubated for 12 hours in a thermostat at 25 °C, after which, observing under a magnifying glass, individual germinated conidia were carefully captured from them using a laboratory needle and sown in Petri dishes on a potato-dextrose agar, after which they were placed in a thermostat at a temperature of 25 °C. Monosporial isolates that developed from individual conidia were then sown in test tubes with a slanted potato-dextrose agar, in which way a collection of pure cultures of monosporous isolates of *Alternaria spp.* was formed which were used in further research.

Pure cultures of monosporial *Alternaria spp*. isolates were kept in a refrigerator at 4 °C on a slanted potato-dextrose agar with regular screening to maintain vitality. Before the start of each experiment, fresh cultures of all isolates, which were used for further studies, were sown.

2.2The influence of temperature on the development and sporulation of the tested Alternaria spp. isolates

Two isolates of representatives of group A (BM-2 and FM-15) and group B (IM-14 and Mr-114) originating from Bosnia and Herzegovina and Serbia, and one control determined isolate of these pathogens CLA-108 (*A. dauci*) and Aa-82 (*A. alternata*) originating from Serbia were used in order to study the influence of different temperatures on the growth and sporulation of studied *Alternaria spp*. isolates.

Analysis of the influence of temperature on the growth and sporulation of six selected *Alternaria spp.* isolates was done by sowing them in Petri dishes on a potato-dextrose agar, which, after sowing, were incubated in the dark at the following temperatures: 3 °C, 12 °C, 20 °C, 23 °C, 27 °C and 33 °C. Colony growth during exposure to different temperatures was monitored daily by measuring the diameter of the colony over a period of 10 days. The influence of different temperatures on the growth of colonies of selected *Alternaria spp*. isolates was calculated as an average daily growth, while the intensity of sporulation was expressed through the number of conidia per 1 cm^2 of the colony. Fixing preparations and determining sporulation were done according to the described procedure. The experiment was set up in five repetitions.

3. Results of work

To analyse the influence of different temperatures on colony growth and sporulation, the studied isolates were grown on a potato-dextrose agar for 10 days, with all isolates analysed for radial growth, average daily growth and sporulation (Table 1).

Table 1. The influence of temperature on the development and sporulation of the tested *Alternaria spp.* isolates

* Values marked with the same letter are not statistically different (Duncan test; p≤0,05);
* Average daily growth calculated by the formula: (D2–D1)/(T2–T1), where D2 and D1 are the diameter of the culture at the last and first measurement, and T2 and T1 are the time (in days) of the last and first measurement;
*** Sporulation: (–) no sporulation, (+) very weak, (++) weak, (+++) medium, (++++) abundant, and (+++++) very abundant sporulation.

Temperature (°C)	Isolates					
	Group A			Group B		
	CLA-108	BM-2	FM-15	Aa-82	IM-14	Mr-114
	Colony diameter (mm)					

3	5,00 ± 0,00e *	5,00 ± 0,00e	5,00 ± 0,00e	7,00 ± 0,00c	7,00±0,63c	7,17 ± 0,41c
12	21,17 ± 1,17d	36,33 ± 2,88d	26,00 ± 2,10d	41,67±1,03 b	31,17±0,75 b	35,33 ± 5,01b
20	29,67 ± 4,27c	58,83 ± 3,66b	58,33±13,84 c	85,00±0,00a	85,00±0,00a	85,00 ± 0,00a
23	49,33 ± 2,50b	61,00 ± 3,41b	73,00 ± 4,82b	85,00± ,00a	85,00±0,00a	85,00 ± 0,00a
27	53,33 ± 4,27a	69,00 ± 4,65a	81,67 ± 5,20a	85,00±0,00a	85,00±0,00a	85,00 ± 0,00a
33	18,50 ± 2,66d	44,83 ± 1,47c	56,67 ± 3,20c	85,00±0,00a	85,00±0,00a	85,00 ± 0,00a
			Average daily growth (mm) **			
3	1,67 ± 0,00c	1,67 ± 0,00c	1,67 ± 0,00c	0,59 ± 0,70d	0,58±0,71d	0,60± 0,70d
12	1,98 ± 1,23c	3,63± 0,91b	2,42 ± 1,41c	3,92 ± 1,78c	2,92±1,35c	3,30 ± 1,64c
20	2,99 ± 1,22b	5,99 ± 2,13a	5,88 ± 1,61b	8,78 ± 1,65b	8,86±2,27b	8,83 ± 2,16b
23	4,90 ± 1,24a	6,25 ± 2,62a	7,45 ± 1,33a	9,24 ± 5,24b	12,44±1,77a	12,37±1,42 a
27	5,28 ± 1,93a	7,24 ± 2,86a	8,62 ± 2,98a	12,39±1,94a	12,41±1,65a	12,15±2,00 a
33	1,75 ± 1,23c	4,49± 0,46b	5,64 ± 1,50b	8,44± 0,76b	8,72 ± 1,77b	8,83 ± 2,72b
			Sporulation ***			
3	-	-	-	++	++	++

12	+	-	-	++	+++++	++++
20	-	+	+	+++++	+++++	++++
23	+	+	-	++++	++	++++
27	+	-	-	+++++	++++	+++
33	+	+	+	+++++	+++++	+++

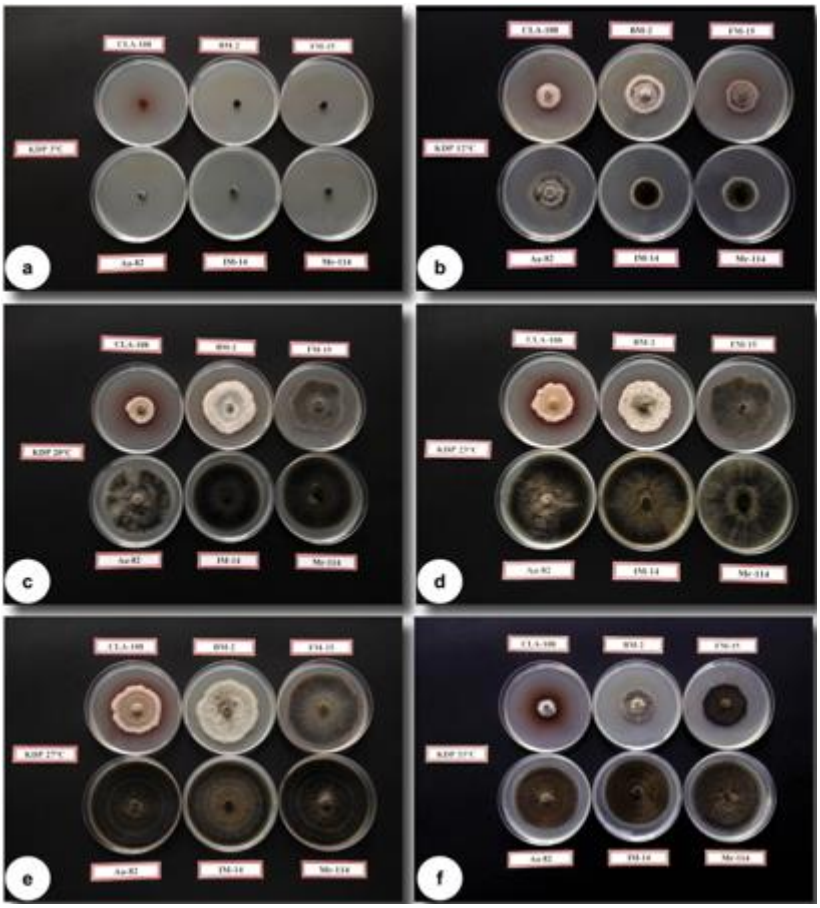


Figure 1. *Alternaria spp*. Appearance of the colonies of the six studied fungal isolates on the potato-dextrose agar grown at six different temperatures, namely: a) 3 °C; b) 12 °C; c) 20 °C; d) 23 °C; e) 27 °C, and f) 33 °C.

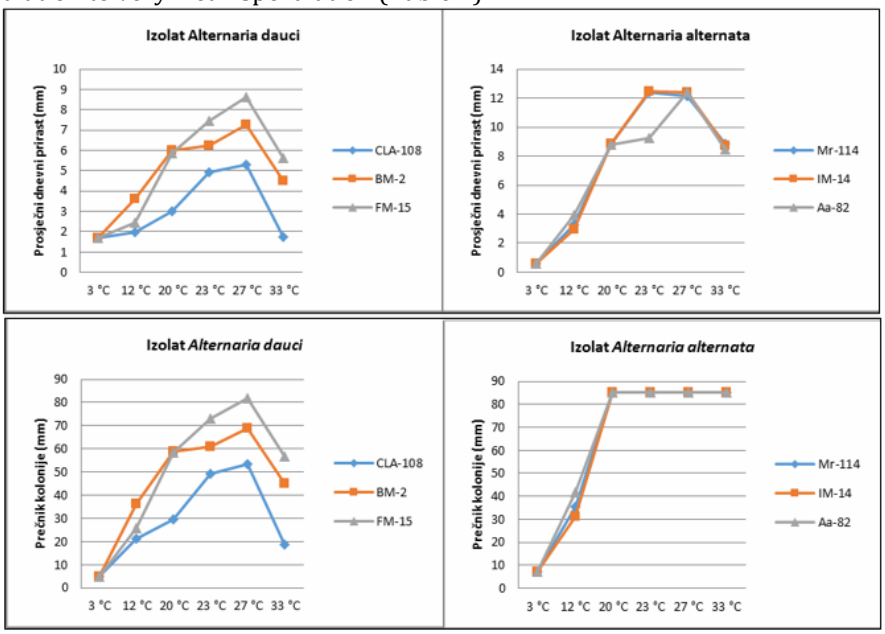
Different temperatures had a statistically significant influence on the radial growth of colonies of all six studied *Alternaria spp*. isolates (Table 1 and Graph 1).

Thus, it was determined, during these studies, that the optimal temperature for the growth of colonies of all six studied isolates, isolates of *A. alternata* and *A. dauci*, is 27 °C, while the most unfavourable temperature for the growth of colonies of all studied isolates is 3 °C.

Also, the average daily growth in colonies of all six studied isolates was statistically significantly influenced by different temperatures, with the daily growth of colonies of all studied *Alternaria spp*. isolates were achieved at a temperature of 27 °C, and the lowest at a temperature of 3 °C (Table 1 and Graph 1).

The influence of temperature on the intensity of sporulation of the studied isolates of group A (CLA-108, BM-2, FM-15) and group B (Mr-114, IM-14, Aa-82) was significant.

Thus, the sporulation of certain group B isolates (Mr-114, IM-14, Aa-82) at all tested temperatures varied from weak to very abundant sporulation, while the sporulation of certain group A isolates (CLA-108, BM-2, FM-15) varied from no sporulation to very weak sporulation (Table 1).



Graph 1. Influence of different temperatures on radial growth of colonies (above) and average daily growth (below) with three selected isolates each from group A (*A. dauci*) (left column) and group B (A. *alternata*) (right column).

From the data presented in Table 1 and Graph 1, it can be seen that the tested group B isolates had the highest radial growth at a temperature of 27 °C, then at a temperature of 23 °C, then at temperatures of 33 °C and 20 °C, while the radial growth was significantly lower at a temperature of 12 °C and the lowest at a temperature of 3 °C.

In contrast, the tested group A isolates had the highest radial growth at a temperature of 27 °C, followed by temperatures of 23 °C and 20 °C, while significantly

lower radial growth was recorded at temperatures of 33 and 12 °C, and the lowest at a temperature of 3 °C.

The average daily growth rate of group B isolates was highest at 23 °C, then at 27 °C and 20 °C, slightly lower at 33 °C, significantly lower at 12 °C and lowest at 3 °C, while group A isolates had the highest daily growth rate at 27 °C, then at 23 °C, 20 °C and 33 °C, significantly lower at 12 °C and lowest at 3 °C.

The presented results graphically and tabularly give a precise insight into the rearing characteristics of the studied isolates, the optimal temperatures for their radial growth, daily growth and sporulation, and possible differences between the two groups of studied isolates with regard to the temperature requirements considered in this paper.

The given results, in addition to other breeding characteristics, provide information on the conditions for the appearance and spread of infections, as well as on the application of effective protection measures against these economically important pathogens.

4. Discussion and Conclusion

Different temperatures had a statistically significant influence on the radial growth of colonies of all six studied *Alternaria spp*. isolates, whereby group A isolates, consisting of isolates FM-15 and BM-2, as well as isolate CLA-108, which was previously identified as the standard for the species *A. dauci*, had the greatest growth at a temperature of 27 °C, then at temperatures of 23 °C and 20 °C, while a significantly smaller radial growth was recorded at temperatures of 33 °C and 12 °C, and the smallest at a temperature of 3 °C. Unlike them, group B isolates, consisting of isolates IM-14 and Mr-114, as well as isolate Aa-82, which was previously identified as the standard for the species *A. alternata*, achieved the highest radial growth at a temperature of 27 °C, then at a temperature of 23 °C, and at temperatures of 33 °C and 20 °C, while the radial growth was significantly lower at a temperature of 12 °C and the smallest at a temperature of 3 °C.

These results are in agreement with the literature references of [4] on the optimal growth of *Alternaria spp*. at 27 °C. Also, [6] states that the examined *A. dauci* isolates exhibited optimal growth at temperatures between 15 and 30 °C, while [1] determined that the examined *Alternaria spp.* isolates of showed the fastest growth at temperatures of 23 and 27 °C. [5] stated that the examined *A. dauci* isolates grew in a wide range of temperatures, and that low temperatures slowed down, but did not stop, the growth of this fungus, which is in complete agreement with the results obtained in these tests.

The influence of temperature on the intensity of sporulation of the studied group A isolates (CLA-108, BM-2, FM-15) and group B (Mr-114, IM-14, Aa-82) was significant. Thus, the sporulation of individual group B isolates at all tested temperatures varied from weak to very abundant sporulation, while the sporulation of individual group A isolates varied from no sporulation to very weak sporulation. These results are in agreement with the results of [3] and [1] who also found variations in the sporulation of the examined *Alternaria spp*. isolates depending on the temperature.

The minimum temperature for the growth of colonies of all studied isolates of groups A and B is 3 °C, the maximum is 33 °C, while the optimum is around 27 °C.

In order to better understand the appearance, growth and development of the studied isolates, in addition to the study of other rearing traits, the given results confirm the correct identification of the two *Alternaria* species and the similarity of the requirements according to the studied temperatures in relation to the optimal radial growth, daily growth and sporulation.

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Toward Hybrid AI-Enhanced Tropical Cyclone Forecasting: Numerical, Data-Driven, and Image-Based Model Comparison

Anas Semlali[1] and Hamid Farrokh Ghatte[2]

[1] Department of Electrical and Computer Engineering, Antalya Bilim University, Antalya, Turkiye.
[2,*] Department of Civil Engineering, Antalya Bilim University, Antalya, Turkiye.

E-mail: hamid.ghatte@antalya.edu.tr

Abstract. This study presents a structured analysis of the evolution and current capabilities of artificial intelligence (AI) in the forecasting of extreme weather events, with a particular focus on tropical cyclones. Traditional numerical weather prediction (NWP) systems, such as the Global Forecast System (GFS) and the Integrated Forecasting System (IFS), remain central to operational meteorology due to their physical accuracy and institutional reliability. However, these systems face well-documented limitations in computational cost and update frequency, especially during rapidly intensifying events. Reanalysis datasets such as ERA5, while not real-time forecasting tools, are extensively used to train AI-based models that can replicate and sometimes exceed medium-range forecast skills. This paper reviews and compares four leading AI architectures GraphCast, Pangu-Weather, FourCastNet and Prithvi, highlighting their model structures, spatial and temporal resolution, and suitability for operational deployment. A case study of Cyclone Chido is used to illustrate persistent gaps in forecast responsiveness and intensity estimation. The paper also explores deep learning methods applied directly to satellite imagery, including CNN-, LSTM-, and GAN-based models, which support localized, short-term predictions through image-based pattern recognition and generative forecasting. A hybrid framework is proposed, integrating physics-based NWP, reanalysis-trained AI, and deep learning on satellite data to enhance accuracy, granularity, and lead time in cyclone forecasting.

Keywords: Artificial Intelligence (AI), Weather Forecasting, Tropical Cyclones, Numerical Weather Prediction (NWP), Satellite Image Prediction, Deep Learning.

1. Introduction

Weather forecasting plays a critical role in safeguarding societies, guiding economic planning, and protecting infrastructure. The consequences of extreme weather events such as hurricanes and tropical cyclones can be catastrophic, causing widespread

damage and loss of life [1]. As climate change increases the frequency and intensity of such events, the demand for more accurate and timely forecasts continues to grow. Traditional numerical weather prediction (NWP) models, such as the Global Forecast System (GFS) and the Integrated Forecasting System (IFS), are based on physical simulations of the atmosphere but often face limitations related to computational cost, resolution, and responsiveness [2]. In contrast, artificial intelligence (AI) especially machine learning (ML) and deep learning (DL) offers a transformative alternative by uncovering patterns in historical data and generating forecasts with remarkable speed [3]. Recent advances such as GraphCast, Pangu-Weather, FourCastNet, and Prithvi Weather have demonstrated the ability to outperform traditional NWP systems in certain forecasting ranges, particularly medium-range predictions, by learning from reanalysis datasets such as ERA5 [4,5,6,7]. In parallel, a third class of models has emerged based on deep learning applied directly to satellite imagery. These DIP models including CNNs for intensity classification [8,9], LSTMs and GC–LSTMs for trajectory estimation [10], and GANs for image-based temporal prediction [11] provide highly localized, visually driven insights that are not constrained by physical assumptions or large-scale data assimilation pipelines. By capturing fine-grained structural features in real-time, these models contribute a distinct layer of capability that complements both physics-based and reanalysis-based AI systems. The evolution of weather forecasting has deep historical roots. From the empirical methods of Babylonian and Chinese civilizations to Aristotle's Meteorologica, humans have long sought to predict the weather [12, 13]. The invention of measurement tools during the Renaissance, including the barometer and thermometer, laid the foundation for modern meteorology. In the early 20th century, Lewis Fry Richardson proposed the first mathematical model for atmospheric prediction. Though initially impractical, his vision of a "forecasting factory" foreshadowed today's high-performance weather simulation systems [14].

Key milestones in the development of forecasting include the use of ENIAC for the first computer-based forecast, the introduction of Model Output Statistics (MOS) in the 1970s, and the rise of global circulation models in the decades that [15,16]. In the 1990s, artificial neural networks (ANNs) were applied to weather-related tasks such as storm and precipitation forecasting [17], laying the groundwork for current AI-based approaches.

This paper explores the progression from classical NWP systems to emerging AI-based models trained on ERA5, while also introducing DIP-based forecasting methods as a complementary class. By comparing these approaches and highlighting their respective limitations, the study builds the case for a tri-hybrid forecasting system that integrates:

(1) physics-based NWP models for global-scale continuity,
(2) ERA5-trained AI models for fast medium-range predictions, and
(3) satellite-driven DIP models for localized and rapid visual interpretation.

The historical trajectory of this evolution is summarized in the time continuum (Figure 1), which frames the progression toward such integrated, layered systems. The top timeline traces the evolution from classical numerical weather prediction (NWP) to AI-based forecasting models trained on reanalysis datasets. In parallel, a bottom track highlights the rise of deep learning on satellite imagery (DIP), including CNN-, LSTM-, and GAN-based approaches.

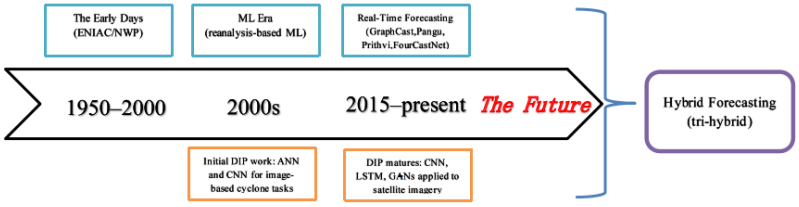

Figure 1. The time continuum of forecasting systems.

These parallel advancements converge in the proposed future direction: a tri-hybrid system that integrates NWP, AI from ERA5, and DIP for enhanced spatiotemporal forecasting.

2. Applications and Use Cases

The field of weather forecasting has historically been dominated by Numerical Weather Prediction (NWP) systems, which simulate the atmosphere using the fundamental equations of fluid dynamics, thermodynamics, and radiation balance. Introduced in the 1950s with the first computer-based forecast on the ENIAC system [15], NWP remains the cornerstone of operational meteorology worldwide. Modern global systems such as the Global Forecast System (GFS), maintained by NOAA, and the Integrated Forecasting System (IFS), developed by the European Centre for Medium-Range Weather Forecasts (ECMWF) ingest real-time data from global observation networks, including satellites, radiosondes, weather stations, ocean buoys, and aircraft [2,16]. Through advanced data assimilation techniques like 4D-Var (used by IFS) and hybrid-EnVar (used by GFS), these models provide high-resolution forecasts (up to 9–13 km) with time horizons extending to 15–16 days and form the basis of national warning systems, civil aviation operations, and disaster preparedness protocols across continents. Unlike real-time NWP systems, ERA5 is a retrospective global reanalysis dataset produced by ECMWF. It reconstructs historical atmospheric states by assimilating multi-source observational data into a consistent modeling framework based on IFS, yielding hourly estimates of dozens of variables since 1940 [18]. While not designed for real-time forecasting, ERA5 is widely used in climate diagnostics, verification of forecasting systems, and increasingly in the training of data-driven AI models. Its high spatial (31 km) and temporal (hourly)

resolution, coupled with multivariate consistency, make it ideal for machine learning research across climate and meteorology [3, 19].

In recent years, AI-based forecasting models trained on ERA5 have emerged as a new class of global weather predictors. Four prominent models currently define the state of the art: GraphCast (Google DeepMind), Pangu-Weather (Huawei), FourCastNet (NVIDIA & Microsoft), and Prithvi Weather (Google India & IMD). These systems apply advanced deep learning architectures including graph neural networks (GraphCast), 3D vision transformers (Pangu), Fourier operators (FourCastNet), and scalable spatiotemporal backbones (Prithvi) to infer atmospheric dynamics directly from data [4,5,6,7]. In benchmark studies, GraphCast and Pangu-Weather have surpassed even IFS in medium-range forecasts up to 10 days, especially for surface temperature, wind, and geopotential height fields. FourCastNet distinguishes itself through speed and model compactness, while Prithvi focuses on monsoon-dominated regions and localized forecasting for India. Together, these systems demonstrate the potential of AI not just to match but in some cases, outperform physically based forecasting [3, 6].

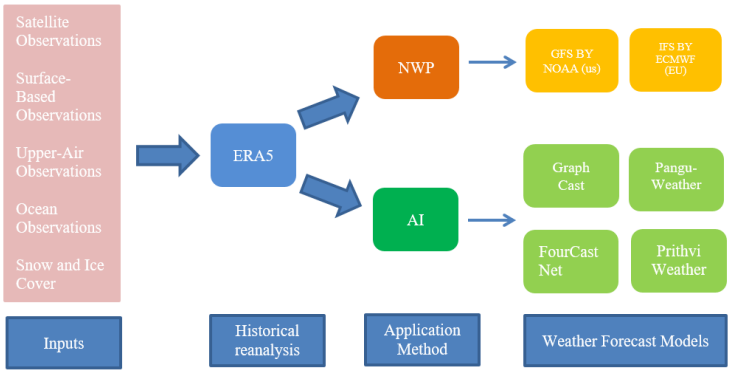

Figure 2. Data flow structure illustrating the role of ERA5 as a historical reanalysis dataset.

This table summarizes key differences in forecast type, modeling method, spatial resolution, forecast horizon, data sources, and operational readiness. Despite this progress, AI models have not yet replaced traditional NWP systems in operational settings. Concerns around explainability, robustness during extreme events, and physical consistency still limit their official adoption [23, 24]. Nevertheless, the growing performance of AI systems opens the door to hybrid forecasting approaches combining the physical rigor of NWP with the pattern recognition and efficiency of deep learning [25].

In parallel, a third approach has emerged through the application of deep learning directly to satellite imagery, often termed Deep Image Processing (DIP). These models leverage convolutional, recurrent, and generative networks to perform storm detection, intensity classification, and short-term trajectory prediction using raw satellite inputs.

CNNs have been applied successfully to classify cyclone intensity based on cloud structure and infrared textures [8, 9], while GC–LSTM models (graph-convolutional long short-term memory) have demonstrated skill in predicting typhoon category transitions over time [10].

Table 1. A ccomparative Overview of Traditional NWP Models (IFS, GFS) and AI-Based Weather Forecasting Systems (GraphCast, Pangu-Weather, FourCastNet, Prithvi Weather) [4,5,6,7,16,20,21,22]

Feature	IFS (ECMWF)	GFS (NOAA)	GraphCast	Pangu-Weather	FourCastNet	Prithvi Weather
Developer	ECMWF(EU)	NOAA(US)	Google DeepMind	Huawei	NVIDIA & Microsoft	Google India & IMD
Forecast Type	Global medium-range to long-range forecasting	Global short to medium range forecasting	Medium-range global forecasts	Global medium-range 3D forecasts	Short to medium range global forecasts	Regional and global AI forecasts
Modelling Method	Physics-based NWP with 4D-Var data assimilation	Physics-based NWP with hybrid-EnVar data assimilation	Graph Neural Network	3D vision Transformer	Fourier Neural Operator (FNO)	Transformer - based architecture
Spatial Resolution	9km (high resolution)	13km	25km	25km	25km	Variable (India focus)
Forecast Horizon	Up to 15 days	Up to 16 days	1-10days	1-7days	Up to 7 days	Up to 7 days
Update Speed	Hours	Updated 4times/day	Minutes	Minutes	Seconds to Minutes	Near real time
Input Data	Satellite, radar, surface, aircraft, ocean data	Same as IFS(wide observation sources)	Trained on ERA5 reanalysis	Trained on ERA5 reanalysis	Trained on ERA5 reanalysis	Trained on ERA5 and regional data
Strength	Very high accuracy, trusted globally, operationally proven	Free and open, widely used, good performance	Very accurate, interpretable, fast inference	Strong vertical modeling, high benchmark scores	Extremely fast GPU-optimized	Tailored for regional alerts, scalable
Limitations	High computational cost, slower update cycles	Slightly lower accuracy than benchmarks	Experimental, not operationally deployed	Not open-source, limited documentation	Less accurate than GraphCast for longer range forecasts	Till early stage, limited global validation

Other studies have used CNN regression to estimate wind speed or locate the eye of a storm in infrared imagery with high accuracy [26]. Generative Adversarial Networks (GANs), combined with LSTMs, have been used to predict future satellite frames, producing temporally coherent sequences that mimic storm evolution without relying on any reanalysis data [11]. A separate line of work [27] has demonstrated cyclone vortex localization using pure CNN pipelines, while a fully end-to-end framework for automated tropical cyclone detection was proposed [28]. Though many of these DIP models remain in experimental stages and lack large-scale operational deployment, they offer high-frequency, image-based insights useful for short-term visual alerts and post-processing of conventional forecasts. These three streams NWP, AI trained on ERA5, and DIP each offer unique capabilities and limitations. NWP provides physics-consistent, globally validated simulations but suffers from

computational cost and update latency. ERA5-trained AI models deliver rapid medium-range inference with global coverage, yet raise concerns around explainability and robustness during extreme events. DIP-based approaches excel in high-resolution local visual tracking and image-based learning but typically lack multivariate coupling or long-range forecast capability. These distinctions justify the development of an integrated tri-hybrid forecasting system that combines:

(1) physics-based global NWP for thermodynamic fidelity,
(2) ERA5-AI models for fast medium-range prediction, and
(3) DIP systems for real-time visual storm analysis.

The rationale and proposed framework for this hybrid integration are further developed in Section 4.

3. Case Study: Cyclone Chido and the Forecasting Gap in Current Early Warning Systems

In December 2024, Intense Tropical Cyclone Chido, a Category 4 storm and the most severe of its kind in nearly 90 years in Mayotte, emerged in the South-West Indian Ocean. The cyclone rapidly intensified, reaching sustained wind speeds of 225 km/h, wave heights exceeding 5 meters, and delivering 176 mm of rainfall within 12 hours across Mayotte, Mozambique, and Malawi [29]. The impact was both devastating and widespread. In Mozambique alone, approximately 190,000 people required immediate humanitarian aid, 35000 homes were either damaged or destroyed, and more than 30 schools were levelled particularly in the Cabo Delgado region [30]. Additionally, over 90,000 children were affected [31].

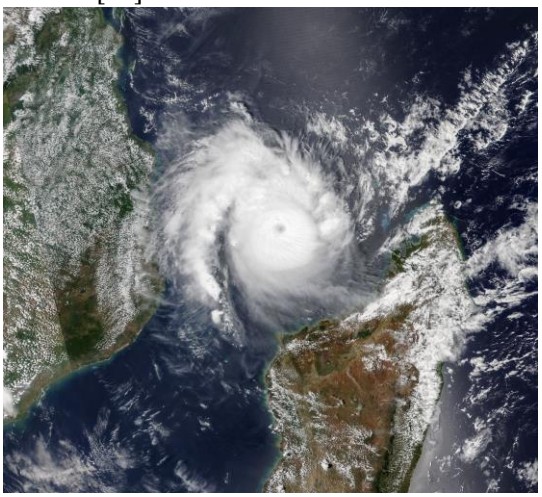

Figure 3. Satellite image of Intense Tropical Cyclone Chido (Photo: NASA) [32].

The threat of waterborne diseases became a major concern, prompting UNICEF to include the region on its watch list for potential outbreaks [31]. Although warnings were issued 50 hours in advance, the alert level had to be raised three times between December 13th and the evening of the 14th [29]. This sequence of events highlights a critical gap in the accuracy and adaptability of current weather prediction systems. It underscores the urgent need for AI-driven forecasting models capable of delivering earlier and more precise alerts to support timely preparation and disaster mitigation efforts.

The storm intensified into a Category 4 system with sustained winds of 225 km/h and made landfall across multiple countries [24].

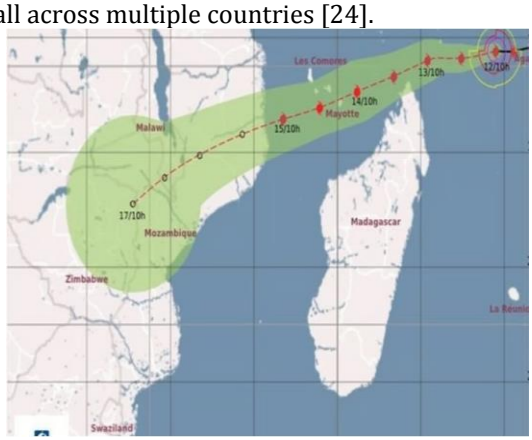

Figure 4. Path of Cyclone Chido across the South-West Indian Ocean (Photo: Down To Earth).

The trajectory shows the storm's movement from December 12th through 17th, 2024, with landfalls in Mayotte, Mozambique, and Malawi [30].

Figure 5. Children impacted by Cyclone Chido in Mozambique (Photo: UNICEF).

More than 90,000 children were affected by the cyclone, with widespread damage to homes and infrastructure.[31]

4. Results and Discussion

The increasing availability of high-resolution observational data, particularly from satellite and upper-air platforms, has substantially enhanced the input fidelity of modern forecasting systems. Among these, traditional numerical weather prediction (NWP) models such as the Integrated Forecasting System (IFS) and the Global Forecast System (GFS) remain central to global operational forecasting due to their adherence to physical laws, proven track records, and long-standing institutional deployment [2, 16]. These models assimilate multi-source observational data through advanced schemes like 4D-Var and hybrid-EnVar, producing forecasts with global consistency and skill. However, their computational demands and inherently slower update cycles limit their agility during fast-developing weather scenarios, particularly tropical cyclones and mesoscale convective systems [33, 34]. Additionally, their forecast skill degrades with lead time levelled of initial condition errors and parameterization limitations in representing cloud microphysics and surface exchanges [35]. In contrast, recent advances in AI-based weather forecasting such as GraphCast [5], Pangu-Weather [6], FourCastNet [4] and Prithvi Weather [7] have demonstrated the feasibility of generating medium-range forecasts with competitive accuracy in a fraction of the computational time. These models, trained predominantly on ERA5 reanalysis, exploit deep learning architectures such as graph neural networks, 3D vision transformers, and Fourier neural operators to extract spatial-temporal dependencies from large climate datasets. GraphCast, for example, has outperformed ECMWF's IFS in medium-range skill scores for temperature and wind, while Pangu-Weather has demonstrated strong vertical structure prediction in benchmark evaluations. Nonetheless, limitations remain: most AI models operate as black boxes with limited explainability [3, 36], lack embedded physical constraints, and have shown vulnerabilities under distributional shifts or novel meteorological regimes [37, 38]. Their operational readiness is still under evaluation, and few have been formally adopted by national weather services. The case of Cyclone Chido provides an instructive example of the forecasting challenges that persist. Although warnings were issued approximately 50 hours prior to landfall, the storm's rapid intensification and late-stage trajectory deviation were not adequately captured by the existing system. This delay in threat escalation illustrates the temporal inflexibility of NWP-driven alert cycles and the absence of supplementary AI layers that could have flagged anomalous structural evolution sooner. While the integration of an AI forecast layer might have accelerated alert updates, exclusive reliance on such systems would introduce unacceptable risks given current limitations in generalization and multivariate coupling. The event underscores the need for multi-source, multi-model fusion rather than model substitution. A third technological axis warrants

attention: deep learning applied directly to satellite imagery (DIP). Unlike reanalysis-trained models, DIP frameworks such as CNNs, LSTMs, and GANs operate on real-time visual data and are optimized for rapid storm detection and localized intensity estimation. Studies by [8] and [9] have shown that tropical cyclone intensity can be accurately classified and estimated using infrared and visible satellite imagery through deep convolutional neural networks. CNN-based intensity classification from IR satellite imagery can rival subjective Dvorak estimates. GC–LSTM models have demonstrated predictive performance in typhoon levels transitions using time-sequenced image inputs [10]. Meanwhile, GAN-LSTM hybrids have successfully generated plausible future satellite frames from raw visual sequences, enabling frame-to-frame evolution modeling[11]. Other efforts have focused on vortex localization [27] and fully automated detection pipelines [28]. While DIP systems are not yet widely operational, their lightweight inference and independence from full assimilation chains render them ideal for nowcasting, post-processing, or fusion with AI/NWP outputs in decision support layers. The comparative strengths and weaknesses of these approaches support a layered, tri-hybrid forecasting architecture: (1) physics-based NWP for physically coherent global forecasting, (2) ERA5-trained AI for medium-range rapid inference, and (3) DIP for near-real-time visual storm monitoring. Each component addresses a different spatiotemporal and functional niche. NWP ensures dynamic balance and energy conservation; AI contributes fast, data-driven generalization; DIP adds localized, high-frequency insight. Together, this synergy can mitigate the blind spots inherent in any single system and provide operational centers with the flexibility, speed, and precision required under evolving climate risks.

5. Conclusion

- Artificial intelligence is reshaping the landscape of meteorology by introducing high-speed, data-driven forecasting systems. The systems are capable of learning complex spatiotemporal patterns from historical and real-time data. AI models such as GraphCast and Pangu-Weather have demonstrated state-of-the-art performance in medium-range forecasting tasks, offering faster inference and improved resolution over traditional numerical weather prediction (NWP) models such as IFS and GFS. These advancements, however, are not without limitations. AI-based systems still face challenges in physical consistency, interpretability, and generalization under extreme or unseen atmospheric conditions. The current study reinforces the case for hybrid forecasting architectures that combine the robustness of physics-based NWP with the efficiency of data-driven AI models. Moreover, it extends this paradigm by incorporating a third component: deep learning applied directly to satellite imagery (DIP). DIP models offer localized, high-frequency insights and have demonstrated practical utility in cyclone detection, intensity classification, and short-term trajectory estimation. By integrating these three model classes NWP, AI trained on reanalysis datasets, and DIP-based visual

models it becomes possible to construct a tri-hybrid forecasting system that delivers global consistency, rapid updates, and real-time visual verification. Such an architecture would not only enhance early warning capabilities but also address key operational constraints in existing systems.

- The hybrid design allows for multi-scale synthesis: NWP ensures dynamical coherence; AI accelerates forecast generation at medium scales; and DIP enables rapid diagnostics and local alerting. This modular integration offers a path toward forecasting frameworks that are simultaneously fast, scalable, and scientifically grounded.
- By uniting the physical fidelity of NWP, the data-driven agility of AI, and the real-time visual interpretability of DIP, the proposed tri-hybrid architecture could redefine the future of meteorological prediction and early warning systems.
- Future work can focus on the development of operational interfaces for multi-model fusion, uncertainty quantification in AI and DIP forecasts, and the incorporation of real-time feedback loops to improve adaptability. On the other hand, validation against high-impact events, such as tropical cyclones and atmospheric rivers, will be essential to assess the reliability and decision-making value of these hybrid systems. As extreme weather risk intensifies under climate change, the scientific and societal urgency for such resilient forecasting infrastructures will only grow.

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Analysis of the Need for Education on Sustainability Reporting in the Context of EU Regulations

Elvira Ćatić-Kajtazović, Vuković Dijana and Kurić Suad

Faculty of Economics University of Bih, Bosnia and Herzegovina

E-mail: elvira.catick@gmail.com

Abstract. Climate change, social inequality, increasing pressure for responsible management and transparent reporting, as well as other global challenges, have resulted in financial reports no longer being sufficient to reflect the full picture of business operations. In this context, non-financial reporting – which includes ESG (Environmental, Social, Governance) factors – is becoming a key tool for establishing sustainable business practices. Bosnia and Herzegovina, as a country in the process of European integration, faces challenges in implementing non-financial reporting in accordance with European directives and international standards. Although there is still no binding law on non-financial reporting at the national level, certain progress is visible through voluntary business practices, as well as through the regulatory framework of entity-level financial reporting agencies. However, the question arises regarding the need for education on the EU regulatory framework for sustainability reporting in Bosnia and Herzegovina. Therefore, a study was conducted using two survey questionnaires on a sample of students from the Faculty of Economics at the University of Bihać. The goal of the first questionnaire was to assess how well students understand the basic concepts related to non-financial reporting, while the second questionnaire aimed to provide insight into whether students consider non-financial reporting topics important for their future careers and whether they are interested in further education in this area.

1. Introduction

Non-financial reporting has developed in response to the need to complement traditional financial performance indicators with aspects related to the broader environmental context in which companies operate. This form of reporting includes information concerning a company's impact on the environment, its relationships with employees and the community, as well as its governance practices and corporate responsibility. The focus is on ESG factors.

Within the modern European legislative framework, a key role is played by the so-called EU taxonomy, a classification system that defines which economic activities are considered environmentally sustainable. This taxonomy was introduced by

Regulation (EU) 2020/852 [1] and aims to ensure transparency and alignment of investments with sustainable development goals [1]. "The EU taxonomy is a cornerstone of the EU's sustainable finance framework and an important market transparency tool. It helps direct investments to the economic activities most needed for the transition, in line with the European Green Deal objective" [2].

In addition to the taxonomy, the Corporate Sustainability Reporting Directive (CSRD) [3], adopted in 2022, represents a significant step forward in the development of non-financial reporting in the EU. "The main aim of the CSRD is to drive accountability and transparency, while promoting sustainable practices and investments" [4]. Among other things, this directive expands the reporting obligation to a larger number of companies, introduces requirements for auditing non-financial data, and mandates reporting according to the European Sustainability Reporting Standards (ESRS). „ESRS specify the information that an undertaking shall disclose about its material impacts , risks and opportunities in relation to environmental, social, and governance sustainability matters" [5].

With the CSRD directive, the term "non-financial reporting" (used in the earlier Non-Financial Reporting Directive – NFRD) has been replaced by "sustainability reporting." According to Zubović, this change in terminology "was made with the aim of equating the importance of sustainability reporting with financial reporting and to emphasize that sustainability also carries financial risk" [6].

In Bosnia and Herzegovina, there is still no binding legal framework for non-financial reporting, while in comparison, Serbia has made non-financial reports mandatory since 2021 for large companies (those exceeding an average of 500 employees during the business year at the balance sheet date), as prescribed by the Law on Accounting [7].

2. Research methodology

The aim of the research is to examine the level of knowledge and awareness among students regarding non-financial reporting topics, with a particular focus on the EU Taxonomy, the CSRD Directive, and the ESRS Standards. The research was designed as a quantitative analysis conducted through two structured questionnaires, which were distributed to students of the Faculty of Economics at the University of Bihać.

The first questionnaire was divided into several sections:

1. General information about the respondents (year of study, study program);
2. Knowledge of basic concepts related to non-financial reporting;
3. Specific questions related to the EU Taxonomy and the CSRD Directive.

In the first phase of the research, data collection was carried out using the paper-and-pencil method, where printed versions of the questionnaires were handed out to students prior to regular class activities. This approach was chosen to enhance students' understanding of the questionnaire items through direct contact, and ultimately to increase the representativeness of the collected data.

The second questionnaire aimed to explore students' attitudes and interests—specifically, how important they consider non-financial reporting topics for their future careers and whether they are interested in further education in this area.

This questionnaire was distributed electronically using the Google Forms tool and was sent via the official email addresses of students at the Faculty of Economics, University of Bihać. This approach ensured that all students across all years of study at the Faculty had equal access and opportunity to participate in the survey.

The study also included an analysis of the academic programs offered at the Faculty of Economics, University of Bihać, and interviews were conducted with teaching staff and associates.

The collected data will be processed using descriptive statistics (frequencies, percentages, means), along with additional analysis of differences in knowledge based on the study program or year of study. The research is based on the assumption that by identifying the need for education on the EU regulatory framework for sustainability reporting, it is possible to define strategic directions for integrating these topics into higher education curricula.

3. Research results

A total of 72 students completed the questionnaire aimed at assessing their self-evaluation of knowledge regarding basic concepts related to non-financial reporting.

Table 1. Descriptive Data Analysis – Questionnaire on Self-Assessment of Knowledge

		Frequency	Percent	Valid Percent
Gender	Male	9	12,5	12,7
	Female	62	86,1	87,3
	Total	71	98,6	100,0
Missing	System	1	1,4	
Total	Total	72	100,0	
Year of study	First	23	31,9	35,4
	Second	18	25,0	27,7
	Third	13	18,1	20,0
	Fourth	11	15,3	16,9
	Total	65	90,3	100,0
Missing	System	7		
Total	72	100,0		

Participants in the study were asked to rate their level of knowledge on topics such as the EU Taxonomy, ESG, Corporate Social Responsibility (CSR), sustainability reports, etc., using a scale from 1 (very poor) to 5 (excellent). The responses are presented in the table below.

Table 2. Presentation of Mean Values in the Area of Self-Assessment of Knowledge

	Minimum	Maximum	Mean	Std. Deviation
Financial reports	1	5	3,08	1,084
Financial reporting	1	5	2,89	,987
Non-financial reporting	1	5	2,76	1,068
Sustainability reports	1	5	2,46	1,093
Corporate social responsibility	1	5	3,29	1,027
ESG	1	5	2,24	1,144
EU Taxonomy	1	5	2,04	1,156

Low self-assessment of knowledge was also confirmed by responses to other questions in the questionnaire. Due to research limitations primarily related to self-assessed knowledge rather than actual knowledge, additional questions were offered to participants regarding environmental objectives according to the EU Taxonomy, GRI standards, and the meaning of the acronyms CSRD and ESRS.

Only 10.15% of respondents correctly identified all environmental objectives according to the EU Taxonomy; 1.15% identified five objectives; 14.49% identified four objectives; as many as 30.43% selected only three objectives; 11.59% chose only two objectives; and 31.88% identified only one objective.Only 27.9% of respondents agreed or strongly agreed that sustainability reporting should be considered equally important as financial reporting, while 16.7% did not answer this question, 7.2% disagreed or strongly disagreed, and the rest were undecided. The questionnaire designed to provide insight into whether students consider non-financial reporting topics important for their future careers and whether they are interested in further education was conducted via Google Forms and completed by a total of 77 students. The descriptive data are presented in the following table:

Table 3. Descriptive Analysis – Survey on the Self-Assessment of the Importance of Topics for Future Careers

		Frequency	Percent	Valid Percent
Gender	Male	14	18,2	18,2
	Female	63	81,8	81,8
	Total	77	100,0	100,0
Year of study	First	33	42,9	43,4
	Second	18	23,4	23,7
	Third	13	16,9	17,1
	Fourth	12	15,6	15,8
	Total	76	98,7	100,0
Missing	System	1	1,3	
Total		77	100,0	

Table 4. Overview of Mean Values on Self-Assessment of the Importance of Non-Financial Reporting Topics for Future Career by Year of Study

	I			II			III			IV		
	Min	Max	Me	Min	Max	Me	Min	Max	Me	Min	Max	Me
IMPORTANCE FOR FUTURE CAREER												
EU Taxonomy	1	5	3,36	1	4	3,22	1	5	3,69	2	4	3,67
Sustainability report	1	5	3,55	1	4	3,39	2	5	3,92	2	5	3,67
ESG	1	5	3,24	1	4	3,33	2	5	3,92	2	5	3,92
CSR – Corporate Social Responsibility	1	5	**3,73**	1	5	3,50	2	5	4,00	2	5	3,92
CSRD – Corporate Sustainability Reporting Directive	1	5	3,45	2	5	3,22	2	5	3,92	2	5	3,92
GRI Standards	1	5	3,21	1	4	3,06	2	5	3,85	2	4	3,58
ESRS Standards	1	4	3,21	1	4	3,00	1	5	3,62	2	4	3,58
Non-financial reporting	1	5	3,39	1	4	3,22	1	5	3,77	2	5	3,83
INTEREST IN FURTHER STUDY												
EU Taxonomy	1	5	3,15	2	5	3,11	1	5	3,69	3	5	3,75
Sustainability report	1	5	3,39	2	5	3,22	2	5	3,92	3	5	3,83
ESG	1	5	3,21	2	5	3,33	2	5	4,00	3	5	4,00
CSR – Corporate Social Responsibility	1	5	**3,61**	2	5	3,44	2	5	3,54	3	5	3,83
CSRD – Corporate Sustainability Reporting Directive	1	5	3,30	2	5	3,33	2	5	3,77	3	5	3,75
GRI Standards	1	5	3,27	2	5	3,11	2	5	3,69	3	5	3,67
ESRS Standards	1	5	3,18	2	5	2,94	2	5	3,77	3	5	3,67
Non-financial reporting	1	5	3,42	2	5	3,28	2	5	3,46	3	5	4,00

When it comes to assessing the importance of topics related to non-financial reporting for students' future careers, as well as their interest in further studying the offered topics, it is noticeable that for first- and second-year students, the average value for all topics is below 3.5—except for CSR in the first year.

At the same time, for third- and fourth-year students, the average values for all topics in terms of their importance for future careers are above 3.5. These results were expected, considering that the surveys were conducted in April and May 2025, at the end of the spring semester of the 2024/2025 academic year. This means that students had largely completed the lectures planned for that academic year and had the opportunity to attend courses such as financial reporting, banking, auditing, and similar

subjects. However, there are no average values above 4, which confirms the findings of the study regarding the level of knowledge about non-financial reporting topics.

An analysis of academic programs revealed that in educational institutions in Bosnia and Herzegovina, the topic of sustainability reporting and its accompanying regulatory framework is still inadequately represented in the curricula. The absence of an integrated and structured approach to this field points to the need for curriculum reform, aimed at preparing professionals capable of meeting the demands of the modern European market.

The results of the study confirm the need for education on the EU regulatory framework for sustainability reporting in Bosnia and Herzegovina, especially in the context of its candidate status for EU membership and the growing need for alignment with European standards.

4. Discussion and Limitations

Based on the analysis of the research results, it can be concluded that there is a need for education on the EU regulatory framework for sustainability reporting. Considering the current status of Bosnia and Herzegovina as a candidate country for EU membership, and its obligation to harmonize its legal framework with the requirements and standards of the European Union—especially in the areas of financial and corporate reporting—this topic gains even greater importance and urgency for improvement.

In line with this, the European Commission, in its report on the state of the economy in Bosnia and Herzegovina (8), has already suggested the revision and modernization of the existing legislative framework to align it with the requirements of EU directives and regulations governing sustainable business practices and the transparency of non-financial reporting.

When it comes to students of economics faculties, acquiring knowledge and a general understanding of this regulatory framework could provide them with an additional competitive advantage in the labor market, a broader range of potential career paths, as well as managerial skills that can help guide the operations of their future companies in line with European standards. Bosnia and Herzegovina's EU candidate status, along with the importance of foreign trade with the EU (especially exports within the context of EU regulations), supports the recommendation to modernize curricula to include topics related to sustainability, ESG factors, non-financial reporting, and corporate social responsibility.

On the other hand, it is important to point out that this research also has several limitations. The first limitation concerns the number of respondents, which—although statistically satisfactory when looking at the total number of students per academic year—is not sufficient in terms of the scope of the survey area, highlighting the need to include students from other higher education institutions in Bosnia and Herzegovina.

The second limitation relates to the methods of surveying students, where part of the student population may have been excluded if they were not physically present at

the faculty during the distribution of the paper-based version of the survey, or if they lacked the technical conditions to participate in the online survey at the time of its distribution. Additionally, the online survey method has the limitation of not allowing further clarification of potentially unclear questions for the respondents.

Third, given that the research deals with a relatively new and complex topic, there is a possibility that some respondents did not fully understand specific terms used, such as ESG, CSRD, EU taxonomy, and similar. Although a researcher was present during the paper-based survey to provide brief explanations of these concepts, it is suspected that the respondents' level of prior knowledge may have influenced the quality of their answers.

5. Conclusion

The regulatory framework for sustainability reporting in the European Union is undergoing rapid development, and its implications are already evident in the way business entities are preparing for more transparent and responsible reporting. With the introduction of new regulatory requirements, such as the Corporate Sustainability Reporting Directive (CSRD) and the European Sustainability Reporting Standards (ESRS), the European Union is laying the foundations for harmonized, reliable, and comparable reporting that will enable more sustainable economic growth, as well as better-informed investors, consumers, and other stakeholders.

An analysis of the existing regulatory framework clearly shows that it is a complex and comprehensive system requiring a deep understanding of the legal, accounting, and managerial aspects of sustainability. For this reason, education on these topics must take a central place not only in formal higher education systems but also through informal forms of professional development. The need for specialized knowledge in the field of sustainability reporting is becoming increasingly pronounced, especially in countries striving for European integration and seeking to maintain competitiveness within the EU single market.

The current situation in Bosnia and Herzegovina indicates a significant gap between the requirements of the European regulatory framework and what the educational system offers. Although certain segments of sustainability are present in academic programs, comprehensive education on the regulatory aspects of reporting is still in its early stages. The lack of integrated programs and a systematic approach hinders the timely preparation of professionals capable of responding to the challenges of implementing European standards.

In conclusion, the need for education on the regulatory framework for sustainability reporting is not merely desirable—it is essential. By incorporating this content into curricula and through continuous professional training, it is possible to ensure the timely alignment of domestic business entities with European practices, strengthen institutional capacities, and foster overall progress toward sustainable societal development.

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Anatomy and physiology of the thyroid gland with a review of the most common diseases

Nikšić Oraščanin Selma, Šahinović Refik and Vilić Husein

Faculty of Biotechnology, Bihac, Bosnia and Herzegovina

E-mail: selma-sammy@hotmail.com,

Abstract. The thyroid gland (glandula thyreoidea) is an endocrine gland located on the front side of the neck, below the larynx. It has a butterfly shape, resembling the letter H, with a narrowed front part (isthmus) lying in front of the trachea. It consists of two lobes positioned laterally along the trachea and larynx. The thyroid gland weighs approximately thirty grams. It secretes the hormones thyroxine (T4) and triiodothyronine (T3) into the bloodstream. Under physiological conditions, the function of the thyroid gland is regulated by the hypothalamus and the pituitary gland. The pituitary gland plays a crucial role in controlling thyroid function, stimulating hormone production and growth through thyrotropin (TSH), which can lead to thyroid enlargement or goiter (struma). The main thyroid diseases include hypothyroidism, hyperthyroidism, goiter, thyroid autonomy disorders, inflammation, and thyroid tumors. In the Una-Sana Canton, from 2021 to 2023, 16,868 patients were registered with various thyroid diseases. In the Federation of Bosnia and Herzegovina, a significant number of thyroid disease cases were recorded in 2021. Primary healthcare services registered 28,012 individuals diagnosed with thyroid disorders, resulting in an incidence rate of 1,292 per 100,000 inhabitants. The highest number of registered cases was among individuals aged 20 to 64 years (20,311), with a prevalence of 72.5%. The prevalence among individuals over 65 years was 25.5%. Statistically, women were more affected than men, with a prevalence of 73.8%.

Key words: thyroid gland, anatomy, physiology, hormone, disease

1. Introduction

The thyroid gland is an endocrine gland, i.e. an endocrine gland, which secretes its products, i.e. hormones, directly into the blood. The main characteristic of endocrine glands is that they consist of glandular-endocrine cells that are arranged in arrays and form groups of cells or follicles. Most of the endocrine glands are organized into organs and, as separate organs, these glands are encased in a special capsule. Such organs also include the thyroid gland. The products of these glands, that is, hormones that represent

chemical substances and have a specific effect on target organs and tissues. They can be peptide, protein, glycoprotein, steroid in nature, or biogenic amines. Their main role is to regulate the vital functions of the organism and to integrate them into a harmonious whole. The thyroid gland is encased in a connective capsule consisting of fibroelastic tissue, and septums extend from the capsule, dividing the gland into lobes.

The thyroid gland secretes two hormones, thyroxine-T4 and triiodothyronine-T3, whose main function is to regulate the intensity of metabolism in the body. Their secretion is regulated by the action of thyroid-stimulating (TSH) or thyroid-stimulating hormone from the adenohypophysis. Also, iodine is very important for the proper growth and functioning of the thyroid gland. The thyroid gland is quite susceptible to various diseases, among which the most common are goiter, hyperthyroidism and hypothyroidism.

2. Material and method of work

This paper is mostly a review paper, and the available literature was used from the materials, and in one part the state of thyroid disease in the Una-Sana Canton was presented, and the records of the Health Insurance Institute of the Una-Sana Canton for the period 2021-2023 were used as a source.

3. Anatomy of the Thyroid gland

The thyroid gland (glandula thyroidea) is a parenchymatous organ that belongs to the group of endocrine glands, i.e. the endocrine glands. Their role is the production of hormones and their secretion into the blood [6]. It is one of the largest endocrine glands, with a mass of 15-20 grams in adults [4]. It is higher in men than in women. In newborns, it weighs 1 g and increases by 1 gram per year until the age of 15 [1]. It is located on the front of the neck at the height of the lower part of the larynx and the upper part of the trachea (Fig. 1)[5,3] It is in the shape of the Latin letter H. It has two lobes, the right and the left (lobus dexter et sinister), connected to the narrowed part (isthmus). Each lobe is about 4 cm long, about 2 cm wide, and 2-3 mm thick [3]. The isthmus is 2 cm long and high and 2-6 mm thick [6.1], (Figure 2). Sometimes the gland has another lobe (Lobus pyrimidalis) that separates from the isthmus as a narrow air of glandular tissue, climbing up to the lingual bone [6,5]. The thyroid gland is enveloped by a connective capsule (capsula fibrosa) consisting of fibroelastic tissue, and septums are provided from the capsule, dividing the gland into lobes. The basic morphological and functional unit of the thyroid gland is the follicle [8] (Figure 3). Follicles are made up of polarized epithelial cells that are known as follicular and parafollicular cells. In these cells, the biosynthesis of macromolecules of protein-thyroglobulin (Tg) takes place. In this large molecule, the hormones of this gland are synthesized - triiodothyronine (T3) and thyroxine (T4). A distinction is made between small-microfollicles and large-macrofollicles. Microfollicles are more active, and macrofollicles contain a larger amount of Tg. Signs of the ability of glandular cells are, in addition to the size of the follicle, the height of the follicular epithelium. Mostly tiny

follicles have a higher prismatic epithelium, and macrofollicles have a low prismatic epithelium. Therefore, the activity of the follicle is in opposite relation to the diameter of the follicle, which means that if the follicle is smaller and the epithelium is higher, these cells are more capable of biosynthesis of thyroglobulin and thyroid hormones. The thyroid gland is a well-circulated organ and is supplied with blood by the upper and lower thyroid arteries (Figure 2).

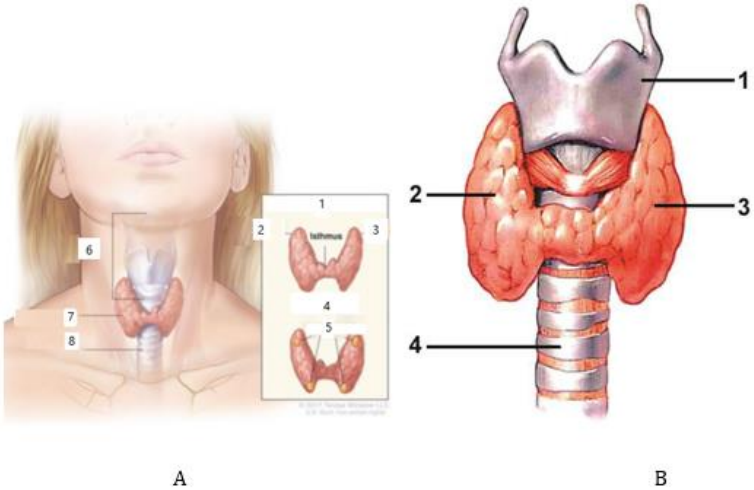

Figure 1. Thyroid gland – position and structure: A: 1. thyroid gland anteriorly, 2. right lobe, isthmus, 3. left lobe, 4. posterior thyroid gland, 5. parathytoid glands; 6. Larynx, 7. Thyroid gland, 8. Trachea; B: 1. Larynx, 2. Lobus dexter, 3. Lobus sinister, 4. Trachea.

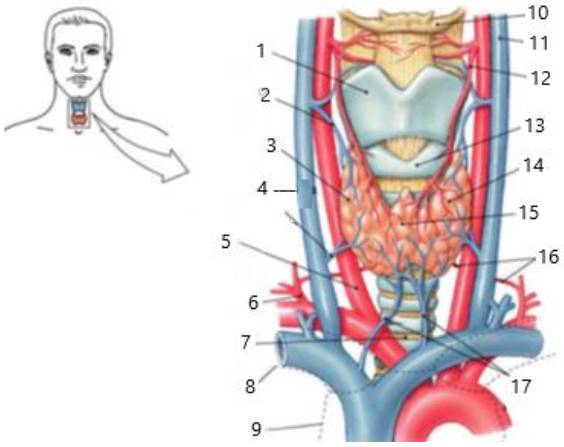

Figure 2. Structure of the thyroid gland: 1. thyroid cartilage, 2. superior thyroid vein. 3. right lobe, 4. middle thyroid vein, 5. common carotid artery, 6. thyroid-neck tree, 7. trachea, 8. outline of the clavicule, 9. sternum outline, 10. hyoid bone, 11. internal jugular vein, 12. superior thyroid artery, 13. cricut cartilage, 14. left lobe, 15. isthmus, 16. inferior thyroid artery, 17. inferior thyroid veins.

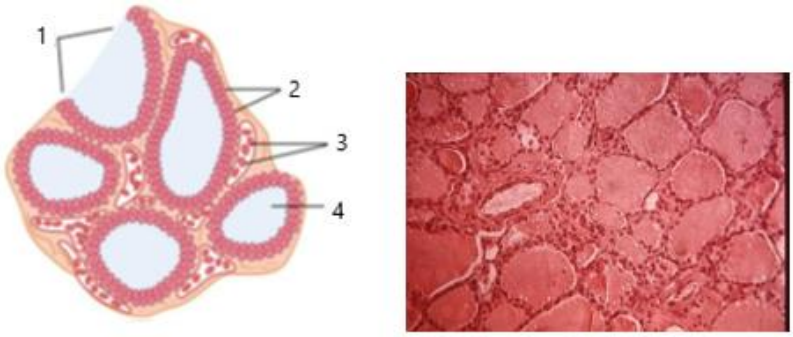

Figure 3. Follicle-histologic section and schematic representation (1. Follicle, 2. Cubic epithelial cells, 3. Erythrocytes, 4. Colloid).

4. Physiology of the Thyroid gland

Thyroid hormones are extremely important for maintaining optimal conditions in the body. That is why there are special feedback mechanisms that act through the hypothalamic-pituitary axis and thus control the secretion of thyroid hormones. The adenohypophysis secretes thyroid-stimulating or thyroid-stimulating hormone (TSH), the secretion of which is controlled by the hypothalamus through thyroid-releasing hormone. A negative feedback loop is established, that is, when the concentration of hormones in the blood increases, the secretion of TSH decreases. Also, thyroid hormones have a negative feedback effect on the secretion of releasing hormone from the hypothalamus [1,7].

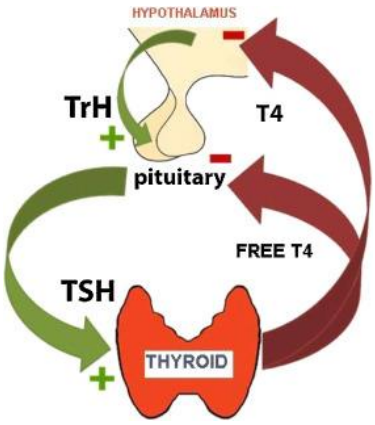

Figure 4. Regulation of thyroid hormone secretion.

The biosynthesis of thyroid hormones is regulated by at least three factors: TSH stimulation, iodine availability, and deiodinase enzyme activity. The thyroid gland is unique among the endocrine glands due to its ability to deposit large amounts of

hormones that are deposited in the follicles in quantities sufficient for the body's normal need for hormones for two to three months [2,8].

Thyroid hormones increase the cellular metabolism of almost all tissues in the body. Likewise, thyroid hormones stimulate the metabolism of glucose, fat, and protein [6]. Thyroid hormones increase the secretion of digestive juices and the motility of the digestive system.

A key target of these hormones is skeletal muscles and they affect their contraction. They also act on full functions. The thyroid gland, as already mentioned, secretes the hormones thyroxine (T4) and triiodothyronine (T3).

5. Diseases of the Thyroid gland

Thyroid disease can affect anyone, men, women, infants, teenagers, and the elderly. It may be present at birth (usually hypothyroidism) and may develop as you age (often in postmenopausal women). The most common thyroid disorders are hyperthyroidism (accelerated thyroid function) and hypothyroidism (slow thyroid function) and goiter.

5.1. Hyperthyroidism

Hyperthyroidism is a condition of overactivity of the thyroid gland, which increases the production and secretion of hormones. Hyperthyroidism occurs at any age, while it is most common in women between the ages of 20 and 50. The most common cause of hyperthyroidism is considered to be an autoimmune disease of the thyroid gland – Basedow's or Graves' disease – an autoimmune disorder in which there is an increased production of thyroid hormones. Symptoms of hyperthyroidism are: weight loss with increased appetite, frequent stools, rapid heartbeat and palpitations, often more than 100 beats per minute, constant fatigue, increased blood pressure, increased sweating, irritability, nervousness, hair loss, insomnia problems and bulging eyes. Treatment of hyperthyroidism is individual, and the main goal is to restore the balance of thyroid hormones in the blood.

5.2. Hypothyroidism

Hypothyroidism is a condition of weakened activity of the thyroid gland that produces and secretes too little hormones. Hypothyroidism occurs more often in women and in older people, and the most common cause of hypothyroidism is Hashimoto's thyroiditis, an autoimmune form of inflammation of the thyroid gland that is hereditary. Given that the function of the thyroid gland is also affected by diet, hypothyroidism can also be caused by iodine deficiency. Symptoms of hypothyroidism can be weight gain despite normal appetite, constant fatigue, palpitations, increased blood pressure, forgetfulness, intolerance to cold, irregular menstruation, dry skin, thin hair and/or hair loss, brittle nails and a hoarse voice. The goal of treatment is to replace the missing hormone, and to better coordinate the therapy, more frequent check-ups are initially needed. In the treatment of hypothyroidism.

Table 1. Distribution of patients with various thyroid diseases in the Una-Sana Canton in a three-year period (2021-2023).

Number of patients										Total
Year	Age range									
	Young (< 15)			Middle-aged (16-60)			Old (>61)			
	M[1]	W[2]	T[3]	M	W	T	M	W	T	
2021	28	36	64	1567	1996	3563	1153	2487	3640	7267
2022	22	28	50	839	1449	2288	1171	1896	3067	5405
2023	-	-	-	-	-	-	-	-	-	4196
Total of patients in a three-year period										16868

[1]M-men; [2]W-women; [3]T-total.

5.3. Goiter

The term goiter denotes an increase in the volume of the thyroid gland. In the general population, it can be found with a frequency of up to 25%, with up to 4 times more frequent in women compared to men. In 50% of people, a nodular shape of the goiter can be found. The formation of goiter is most often associated with a lack of iodine intake in the body. With the introduction of iodization of table salt (in our country since 1953), the incidence of goiter has been significantly reduced, but not completely eradicated. Today it is known that in addition to iodine deficiency, there are other causes that lead to goiter: a congenital genetic disorder of iodine accumulation inside thyroid cells, the use of various medications, autoimmune disorders of the thyroid gland, conditions that cause an increase in TSH levels (tumors of the pituitary gland and hypothalamus), inflammation of the thyroid gland, granulomatous diseases (sarcoidosis, tuberculosis), compounds from food such as cyanoglucosides and thioglucosides (especially found in cabbages) and reduced intake of selenium.

Goiter usually presents without any symptoms, although the complaints often depend on its size and the presence of pressure on local anatomical structures. Sufferers may present with thickening or deformation of the front of the neck, neck discomfort, a feeling of suffocation, coughing, shortness of breath or hoarseness. The most important diagnostic elements are specialist and ultrasound examination. Goiter that does not cause discomfort and does not represent a cosmetic defect does not require treatment. If indicated, goiter is treated with thyroid hormones, surgery or the application of radioactive iodine, as well as thyrostatic drugs and radioactive iodine if "warm/hot" nodules are found. Finally, in the following table, we have shown the state and prevalence of thyroid diseases in the Una-Sana Canton, in the period 2021-2023.

The data from the table shows that thyroid diseases are quite present in the Canton and that, unfortunately, they are widespread in all populations, from those under 15 years of age to those over 60 years of age. A similar situation is in the Federation of Bosnia and Herzegovina, where, in 2021, a significant number of patients with thyroid diseases was recorded. Primary health care registered 28,012 patients with diagnoses related to thyroid disorders, which resulted in an incidence rate of 1,292 per 100,000 inhabitants. The highest number of registered cases was among people aged 20 to 64 (20,311), with an incidence of 72.5%. The incidence of the disease among people over 65 years of age was 25.5%. Women are statistically more affected than men, with an incidence of 73.8%.

6. Conclusion

The thyroid gland is an endocrine gland that synthesizes and secretes 2 essential hormones, Triiodothyronine and Thyroxine. These hormones have a number of functions, but in principle they regulate the level of metabolism in the body. The thyroid gland is susceptible to a number of diseases, the most common of which are hypothyroidism, hyperthyroidism and goiter. Thyroid diseases are quite widespread in the Una-Sana Canton and the Federation of Bosnia and Herzegovina.

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S P O N Z O R I

Grad Bosanska Krupa

Općina Bosanski Petrovac

Grad Cazin

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Berlina d.o.o. Bihać