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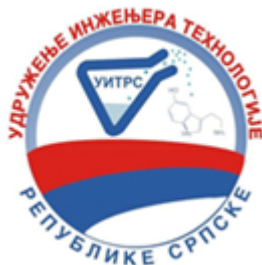
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**XIV INTERNATIONAL CONFERENCE ON SOCIAL AND TECHNOLOGICAL DEVELOPMENT
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NONDESTRUCTIVE OPTICAL SPECTROSCOPY IN PLANT STRESS RESEARCH: CIRCADIAN RHYTHM AS A DIAGNOSTIC MARKER

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ABSTRACT

In the context of environmental changes and the increasing demand for sustainable agricultural practices, real-time monitoring of plant health is increasingly important. This work provides an overview of the development and application of nondestructive optical spectroscopy for early detection of stress across a wide range of plant species. The approach combines high-resolution time tracking of leaf transmission with circadian rhythm analysis, allowing the identification of subtle physiological changes that precede visible stress symptoms.

This work presents results from several experimental studies, including hydroponically grown herbs, forest species, aquatic plants, ornamentals, and agricultural crops. The methodology enables the early detection of stress caused by nutritional deficiencies, pathogenic infections, and sudden changes in light intensity. Integration of the 640 nm and 665 nm spectrum bands significantly improved system sensitivity, allowing precise characterisation of metabolic responses. These advances are supported by comprehensive metrological validation, which ensures the repeatability and robustness of the data under experimental conditions.

The lecture highlights circadian rhythm not only as a fundamental biological process, but also as a new diagnostic marker of the physiological state of the plant. Through a variety of case studies and practical applications, we demonstrate how this optical platform contributes to improving understanding the response of plants to stress and offers new perspectives in plant science, forest monitoring, and precision agriculture.

Key words: Nondestructive spectroscopy, circadian rhythm, plant stress detection, real-time plant monitoring, leaf transmittance.

INTRODUCTION

Modern plant cultivation stands at the crossroads of profound societal and technological transformation. The need to ensure global food security, adapt to climate change, and minimise environmental impact makes the prompt and efficient detection and management of plant stress a critical priority. According to the Food and Agriculture Organisation (FAO) and recent international reports, up to 40% of potential crop yield is lost annually due to environmental stress factors such as drought, salinity, pathogens, and nutrient imbalance, directly impacting economies, societies, and the stability of food systems (Kumar et al., 2022). These challenges underscore the importance of innovations that bridge advanced science with practical application, empowering both growers and decision-makers.

Thus, early detection of plant stress is not only a scientific or agronomic priority but also a key component of sustainable development, environmental protection, and societal resilience. Effective and precise monitoring of plant physiological status can reduce agricultural losses,

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improve yield quality, optimise the use of chemical input, and support data-driven decision making all fundamental goals in the transition to smart and sustainable agriculture.

Traditional plant health monitoring has typically relied on destructive, time-consuming, and often subjective methods. These approaches involve physicochemical analyses of plant tissues, which require laborious sample preparation and often result in damage to the plant material (Kvet et al., 1971). Moreover, such methods provide only fragmented and retrospective insights, often missing the early stages of stress response when intervention is most effective. Given that the general state is closely related to the intensity of photosynthetic processes in its leaves, there is a critical need for a continuous and nondestructive monitoring of these key physiological indicators (Gitelson et al., 2023).

Nondestructive optical methods (NOM) have recently emerged as transformative tools in this regard. These techniques allow for real-time in vivo assessment of plant metabolism and stress, preserving plant integrity, and enabling the detection of subtle physiological changes before visible symptoms arise. At the Faculty of Physics, University of Belgrade, our group has developed and validated an innovative NOM system that continuously monitors plant health and metabolic processes by measuring optical transmission and reflection primarily at wavelengths relevant for chlorophyll absorption (e.g., 665 nm and more recently, 640 nm) (Kasalica et al., 2021; Miletic et al., 2022b; Miletic et al., 2023a; Miletic et al., 2023b; Miletic et al., 2023c; Miletic et al., 2023d; Miletic et al., 2024a; Miletic et al., 2024b, Ristic et al., 2023, Ristic et al., 2024).

An identifying feature of this approach is the analysis of circadian rhythm patterns in the optical properties. Since photosynthetic activity within leaves is tightly coupled with overall plant health, disruptions or modifications in circadian patterns manifested as changes in the amplitude, frequency, or phase of optical signals can serve as sensitive early markers of diverse stress conditions. The design of the system, with multiple independent measurement points and flexible leaf holders, ensures statistically robust and reliable data, accommodating natural leaf movement and environmental variability.

Over recent years, this NOM technology has been successfully applied to detect and characterise a wide range of plant stresses, including: light intensity stress, nutritional deficiencies, water scarcity/drought stress, pathogen infections, herbicide exposure, etc. (Miletic et al., 2022a; Veljovi Jovanovi et al., 2023; Miletic et al., 2023b; Madzarevic et al., 2023; Mladenovic et al., 2023; Komazec et al., 2024).

The efficacy and sensitivity of the NOM system have been benchmarked against traditional parameters, such as pigment content, dry weight, and Photosystem II (PSII) efficiency, with optical methods often revealing changes well before conventional indices (Kasalica et al., 2021; Miletic et al., 2022a; Veljović Jovanović et al., 2023, Ristic et al., 2024)

Beyond the scientific and technical achievements, the social impact of this methodology is substantial. By providing an accessible, rapid, and precise means of monitoring plant health, NOM facilitates the digitalisation and smart management of agriculture optimising resource use, reducing environmental impact, and supporting the resilience of food systems. This is especially relevant as societies face the compounded pressures of climate change, resource limitations, and the need for a sustainable intensification of agricultural production (FAO, 2022).

In summary, the development and application of nondestructive optical monitoring systems mark a significant advance in plant science and technology, opening paths for more efficient, sustainable, and socially responsible agriculture.

MATERIALS AND METHODS

Measurement System and Optical Setup

The metrological foundation of this system is built on precise measurement principles and a robust experimental setup, designed for high sensitivity and statistical reliability in tracking circadian rhythms as key indicators of metabolic activity and stress (Kasalica et al., 2021).

The core of the NOM developed at the Faculty of Physics, University of Belgrade, is a custom designed multichannel system for real-time monitoring of the optical properties of the plant leaf (Figure 1). The apparatus consists of 20 independent measurement channels (Figure 2), each

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accommodating a single leaf attached via a transparent adjustable holder that allows for five degrees of mechanical freedom, allowing the system to follow the natural movement and growth of the plant leaf. Each measurement channel uses red LED light sources (primarily 665 nm, with recent upgrades including 640 nm for enhanced photosynthetic specificity), coupled via optical fibres to the plant leaf. Transmitted and reflected light is collected by dedicated fibres and detected by photodiodes within a thermostated, shielded compartment. Signals are filtered at precise wavelengths and recorded at 15-minute intervals using automated data acquisition and custom software. Calibration is routinely performed with certified neutral density filters and standard reflective targets to ensure data comparability across all channels (Kasalica et al., 2021; Miletic et al., 2024b).

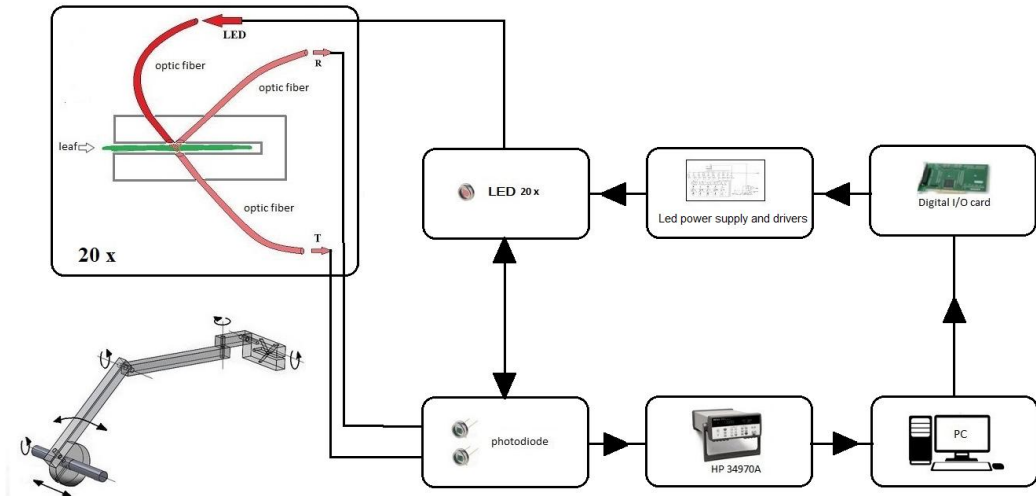


Figure 1. NOM block diagram (Kasalica et al., 2021)

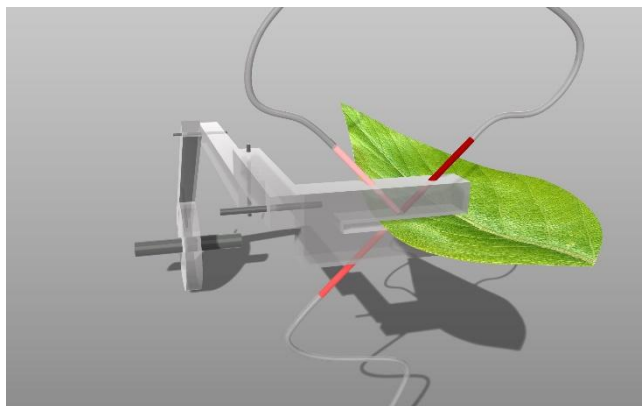


Figure 2. Optical-fibre-integrated acrylic leaf holders

Plant Material and Stress Treatments

Experiments are conducted in controlled indoor environments or growth chambers with regulated temperature, photoperiod, humidity, and illumination. Plants are cultivated hydroponically or in soil, depending on the specific experimental goal. Environmental parameters

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(e.g., temperature, humidity, light intensity/photosynthetic photon flux density – PPFD) are regularly monitored and maintained to ensure reproducibility and minimise external variability.

Various plant species have been studied using this system, including *Ocimum basilicum*, *Vriesea carinata*, *Pelargonium zonale*, and *Castanea sativa*, among others. For stress treatments, experimental groups are subjected to specific stressors:

- Nutritional deficiency: Nutrient solutions lacking key elements (N, Mg, P, Fe) are prepared, and control plants are maintained in complete nutrient solutions (Miletic et al., 2022a).
- Water scarcity: Watering is stopped for a defined period to induce drought stress (Miletic et al., 2023c).
- Light-intensity stress: Plants are exposed to varying light intensities, controlled by dimmable LED panels, with measurements performed across a range of PPFD values (Kasalica et al., 2021; Veljović Jovanović et al., 2023).
- Pathogen infection: Various plants are inoculated with pathogens, such as *Phytophthora plurivora*, using established flood and inoculation protocols (Miletic et al., 2023b).
- Herbicide application: Some experiments include treatment with commonly used herbicides, with subsequent monitoring (Miletic et al., 2023d).

Data Acquisition and Analysis

Optical transmission and reflection coefficients are recorded for each channel over time, yielding time-resolved profiles suitable for circadian rhythm analysis. Parameters such as amplitude, period, and deviations from the baseline are extracted to serve as early stress indicators. For method validation, traditional physiological and biochemical measurements (e.g., pigment content, dry weight, PSII efficiency) are conducted in parallel, as detailed in previous studies (Kasalica et al., 2021; Miletic et al., 2022a; Veljović Jovanović et al., 2023; Ristic et al., 2024).

Calibration and System Validation

Calibration procedures account for interchannel variability, LED emission characteristics, and optical path differences, using neutral-density filters and standard diffusive targets. Systematic validation is performed by comparing the NOM data with conventional methods, ensuring the accuracy and sensitivity of the approach. Further technical and methodological details are available in our referenced publications (Kasalica et al., 2021; Miletic et al., 2022a; Veljović Jovanović et al., 2023; Ristic et al., 2024).

RESULTS

The NOM system enabled continuous, real-time monitoring of plant responses under various stress conditions. Alterations in the circadian rhythm of optical transmission were observed as early and sensitive indicators of stress, frequently preceding visible symptoms or changes detected by conventional methods.

Detection of nutrient deficit stress

Continuous monitoring of leaf optical properties revealed that plants subjected to nutrient deficiency exhibit characteristic alterations in the circadian rhythm of transmission well before any visible symptoms are observed. In hydroponically grown *Ocimum basilicum*, significant deviations from the control circadian pattern manifested as reduced amplitude and baseline shifts were detected as early as 2 to 4 days before the onset of leaf chlorosis or measurable pigment loss. The observed optical changes arise from the physiological consequences of nutrient deprivation, primarily chlorophyll degradation, altered pigment composition, and structural rearrangements within mesophyll tissue, which jointly modify the absorption and scattering of red light through the leaf. These processes reduce the effective optical density of the leaf, resulting in modified transmission amplitude and rhythm stability. The same mechanism was previously confirmed through parallel measurements of chlorophyll content and PSII efficiency, which showed a strong correlation with optical response (Miletic et al., 2022a). Restoration of missing nutrients resulted in

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recovery of normal circadian oscillations, confirming both the sensitivity and reversibility of the system (Madzarevic et al., 2023). This recovery reflects the reestablishment of photosynthetic balance and pigment synthesis, further validating the circadian optical signal as a reliable indicator of metabolic adjustment. Figure 3 illustrates the typical disruption of the circadian rhythm due to nutrient deficiency.

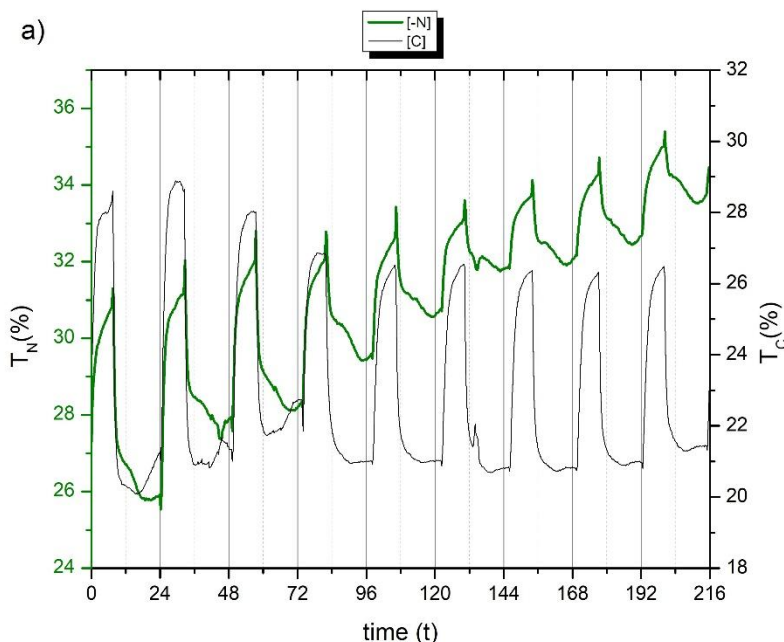


Figure 3. Comparative circadian rhythm profiles of *Ocimum basilicum* under full nutrient supply and nitrogen deficiency (Miletic et al., 2022a)

Light Intensity Stress and Photometabolic Shifts

When exposed to excessive light, species such as *Vriesea carinata* and *Pelargonium zonale* demonstrated distinct changes in the amplitude and phase of circadian rhythm profiles. These changes are primarily associated with photoinhibition effects and dynamic photoprotective responses that occur when light absorption temporarily exceeds the capacity of the photosynthetic electron transport chain. Increased photon flux density induces adjustments in chloroplast positioning and activation of non-photochemical quenching mechanisms, both of which alter light scattering and absorption properties within the leaf (Veljović Jovanović et al., 2023). The NOM system successfully tracked the transitions between C3 photosynthesis and CAM (Crassulacean Acid Metabolism) in *V. carinata*, with high light intensities that cause an increase in amplitude and a change in the timing of daily maxima and minima (Figure 4). This transition reflects a physiological shift in carbon fixation and stomatal behaviour, where nocturnal CO₂ uptake and daytime decarboxylation modify the temporal pattern of photosynthetic activity. As CAM metabolism becomes dominant, light transmission increases during the night due to stomatal opening and water retention, while daytime transmittance decreases as the stomata closes and internal CO₂ recycling prevails. These metabolic adjustments produce characteristic optical phase shifts and modulation that the NOM system captures in real time. CAM species open their stomata predominantly at night and often exhibit circadian phase shifts compared to C3, which is relevant for interpreting transmittance rhythms (Ristic et al., 2024).

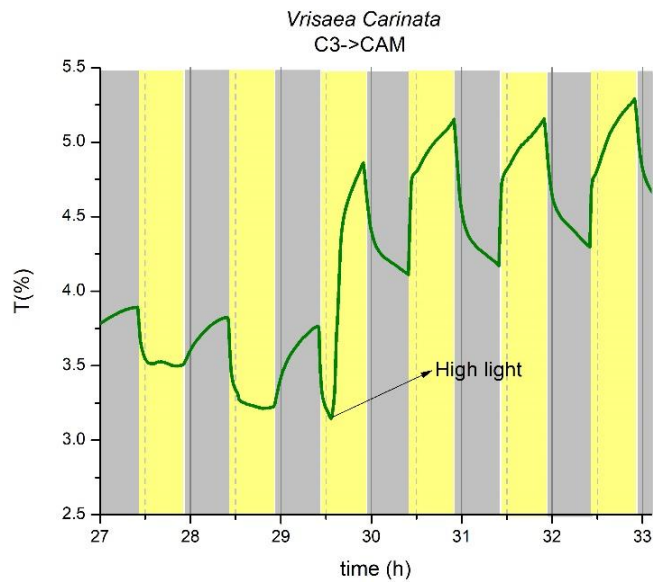


Figure 4. Circadian rhythm of *Vriesea carinata* under changing light intensity (Ristic et al., 2024)

Furthermore, the recently integrated 640 nm channel enabled even earlier detection of stress-induced changes, as shown in comparative results for the 665 nm and 640 nm channels (Miletic et al., 2024b).

Figure 5 presents representative circadian profiles under varying light regimes, highlighting differences between detection wavelengths.

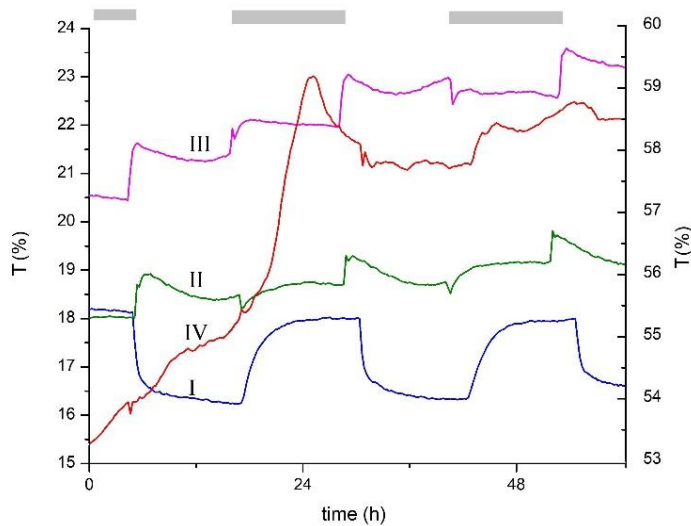


Figure 5. Circadian rhythm of the *P. zonale* under changing light intensity (Veljović Jovanović et al., 2023)

Drought (Water Scarcity) Stress

Under water deficiency conditions, significant disturbances in circadian rhythm were observed several days before the appearance of visual signs of wilting or necrosis. In *Ocimum Basilicum*, the amplitude of the circadian signal decreased and the baseline changed as the availability of water decreased. These optical alterations primarily result from reduced leaf turgor and intracellular water content, which influence refractive gradients within the mesophyll and modify the balance between transmitted and scattered light. As dehydration progresses, stomatal closure limits CO₂ uptake and photosynthetic electron flow, reducing chlorophyll excitation and light absorption efficiency. The combined effects lead to a gradual decrease in transmission amplitude and a change in circadian baseline, both of which were consistently detected by the NOM system prior to visible stress symptoms (Miletić et al., 2023c). In particular, the system could reliably differentiate between mild and severe drought stress states based on rhythm characteristics. Figure 6 shows the temporal evolution of the transmission coefficient during prolonged drought stress.

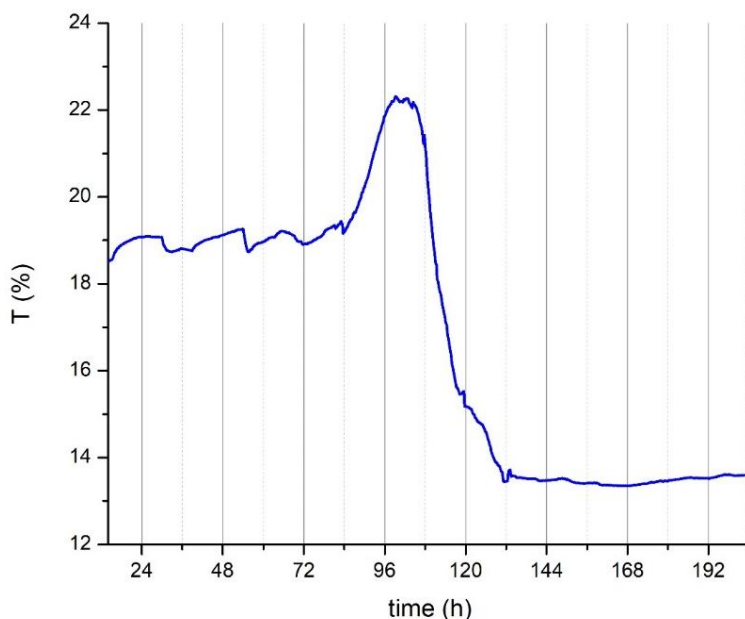


Figure 6. Circadian rhythm of drought-stressed *Ocimum Basilicum* (Miletić et al., 2023c)

Pathogen Infection

Following inoculation with *Phytophthora plurivora*, *Castanea sativa* leaves exhibited rapid and marked alterations in amplitude and structure (Miletić et al., 2023b). These optical changes consistently preceded the appearance of visible disease symptoms, providing a critical window for early intervention and plant protection. Physiologically, infection disrupts chloroplast integrity and damages mesophyll cell membranes, leading to localised water loss and oxidation of pigments. These structural and biochemical alterations modify the internal light scattering pattern and reduce overall transmittance, which manifests as amplitude damping and irregularities in circadian rhythm (Miletić et al., 2023b). The observed phase shifts are related to impaired photosystem activity and oxidative imbalance, making the optical signal a sensitive indicator of early pathogenic stress.

Figure 7 shows the modification of circadian profiles in infected versus control leaves.

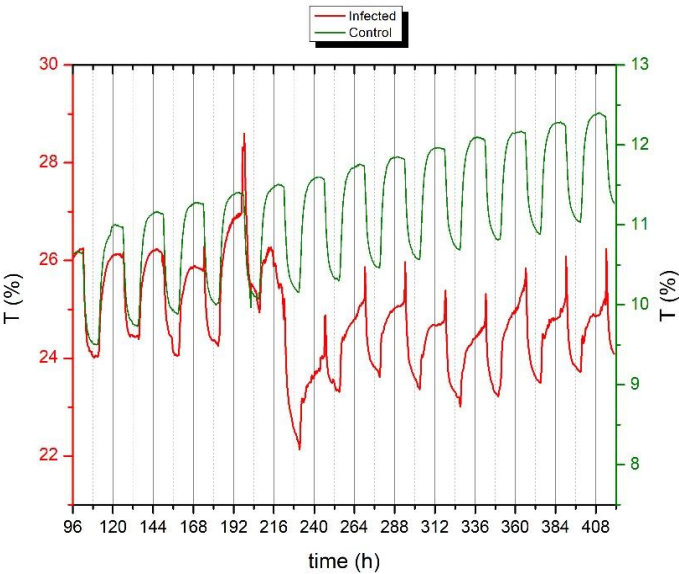


Figure 7. Phase shifts in circadian rhythms of *Castanea sativa* leaves following pathogen infection (Miletic et al., 2023b)

Herbicide-Induced Stress

The application of herbicides led to a pronounced dampening and desynchronisation of the circadian rhythm in exposed plants. Altered periodicity and reduced amplitude were evident within 24 hours after treatment, underscoring the sensitivity of the NOM system to various chemical stressors. These effects arise from the inhibition of photosynthetic electron transport and the degradation of photosynthetic pigments caused by herbicide exposure. The breakdown of chlorophyll biosynthesis reduces the absorption of red light, while membrane damage alters internal scattering pathways within the leaf. As a result, the overall transmittance signal becomes unstable, with a decrease in amplitude and rhythm coherence, providing a clear optical signature of herbicide-induced stress (Miletic et al., 2023d). Figure 8 illustrates typical rhythm alterations after herbicide application.

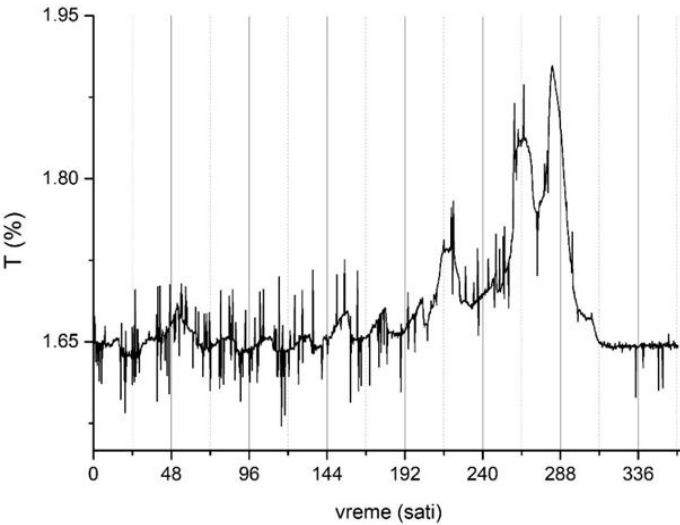


Figure 8. Circadian rhythm of *Bryophyllum daigremontianum* (Miletic et al., 2023d)

Validation with Conventional Physiological Indices

Across all stressors considered, the NOM system detected changes earlier than traditional physiological measures, such as chlorophyll content, dry weight, and PSII efficiency. Quantitative comparison demonstrated a strong correlation between early NOM signal changes and subsequent alterations in these classical indices, but with NOM offering a substantial advantage in timing and resolution (Kasalica et al., 2021; Miletic et al., 2022a; Veljović Jovanović et al., 2023, Ristic et al., 2024).

DISCUSSION

Early Stress Detection: Scientific and Practical Relevance

The results presented in this study demonstrate the high sensitivity and specificity of the NOM system for the early detection of various plant stresses. The ability to track subtle, stress-induced alterations in circadian rhythms often days before visible or classical physiological symptoms appear represents a major advancement over traditional, destructive, and delayed diagnostic approaches. This provides not only a scientific breakthrough in plant stress physiology, but also a powerful tool for timely intervention in both research and agricultural practice.

Comparison with Conventional Methods and Other Optical Techniques

Unlike standard physiological indices such as chlorophyll content, dry biomass, or PSII efficiency, which often lag behind the actual onset of stress, NOM enables continuous, nondestructive monitoring of metabolic processes. In direct comparison, classical methods typically detect stress at a later stage, when irreversible damage may already have occurred. Incorporating multiple wavelengths, especially the addition of 640 nm channels, further enhances the sensitivity of the method, allowing the discrimination of stress type and even metabolic transitions (e.g. C3 to CAM) in real-time.

Beyond its early-warning capacity, the system demonstrates several distinct advantages over other optical approaches. Its multichannel design ensures robust, parallelised measurements and strong statistical reliability, while its high temporal resolution makes it ideally suited for tracking circadian dynamics. The method has proven versatile across a wide range of plant species and stress conditions, and its performance has been systematically validated against established biochemical and physiological markers, confirming both its accuracy and practical relevance.

Broader Implications for Smart Agriculture and Sustainable Development

Beyond the laboratory, the deployment of NOM technology in field or controlled environment agriculture can contribute significantly to smart, resource efficient, and resilient food production systems. Early and precise stress detection allows targeted interventions, such as optimised irrigation, fertilisation or pest management, to minimise input waste and environmental impact. This aligns with the principles of precision agriculture and supports the broader goals of sustainable development, climate adaptation, and food security.

Furthermore, the nondestructive, continuous, and scalable nature of the method makes it a strong candidate for integration with digital and IoT (Internet of Things)-based monitoring platforms, enabling automated, data-driven crop management and large-scale phenotyping.

Limitations and future directions

Although the current system demonstrates robust performance under controlled experimental conditions, more work is needed to adapt and validate the approach in open field settings, where environmental variability is greater. The development of portable and user-friendly devices, as well as the application of machine learning to automate data interpretation, represent promising avenues for future research.

Additionally, extending the spectral coverage and integrating NOM with other sensing modalities (e.g., hyperspectral imaging, environmental sensors) could further expand its diagnostic power.

CONCLUSION

This work demonstrates that advanced, nondestructive optical monitoring of circadian rhythms provides a highly sensitive and early indicator of plant stress across a range of environmental and physiological challenges. The ability to detect stress-induced metabolic changes days before the appearance of visible symptoms or traditional physiological markers represents a significant advance for both plant science and agricultural practice.

By continuously and nondestructively tracking the optical properties of plant leaves, particularly at wavelengths relevant for photosynthetic processes, the NOM system enables rapid identification, differentiation, and quantification of stress responses. This not only supports more effective research and breeding for stress-tolerant genotypes, but also empowers the implementation of precision agriculture and smart crop management strategies.

The integration of such technologies into agricultural and environmental monitoring systems holds great promise in reducing yield losses, optimising resource use, and supporting the transition to sustainable, resilient, and climate-smart food production. The continued development and deployment of NOM approaches will further strengthen the link between scientific innovation and real-world impact, contributing to the broader goals of sustainable development and food security.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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***ECOLOGY, ENERGETIC EFFICIENCY AND
GREEN ENERGY
EKOLOGIJA, ENERGETSKA EFIKASNOST I
ZELENA ENERGIJA***

THE IMPACT OF HALAL CERTIFICATION ON ENVIRONMENTAL STANDARDS IN THE SERBIAN MEAT INDUSTRY

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ABSTRACT

This paper explores the impact of Halal certification on environmental standards in the Serbian meat industry, with particular emphasis on sustainable resource use and the reduction of the environmental footprint in meat production. Although Halal certification is primarily a religious regulatory framework, it encompasses specific requirements related to animal welfare, strict hygiene practices, and meat handling procedures - all of which can contribute to enhancing environmental standards in the meat industry. The aim of this research is to analyze the environmental aspects associated with Halal certification and assess its influence on the sustainability of meat production in Serbia. The methodology includes an analysis of relevant literature focusing on the ecological dimensions of Halal production, as well as an examination of the practices employed by domestic meat producers who hold Halal certificates. Special attention is given to the environmental protection measures these producers implement and the challenges they face in adopting sustainable practices. The paper also discusses opportunities for improving existing ecological practices by further aligning Halal standards with sustainable production principles. In this way, Halal certification can contribute not only to meeting the religious requirements of consumers but also to reducing the environmental impact of the meat industry.

Keywords: Halal certification, environmental standards, sustainable production, meat industry, environment.

INTRODUCTION

Halal standard is a set of rules and guidelines for the production and preparation of food in accordance with Islamic religious norms. Its requirements are based on the Quran and Sharia law, which define what is halal, i.e. permitted, and what is haram, i.e. forbidden. The term "permitted" refers to food prepared according to Sharia rules, which is the dietary practice followed by most Muslims around the world.

Halal, among other things, prohibits the use of pork, blood, alcohol, meat from dead animals, carnivores, donkeys, dogs, birds of prey, food prepared with wine, cakes containing any kind of alcohol, as well as products that contain emulsifiers made from pork or other animal fat.

A large number of Halal standard requirements overlap with the requirements of the HACCP system and the ISO 9001 standard, which significantly facilitates the certification preparation process for organizations that have already implemented one of these systems.

Halal can be applied to various products and services – food, cosmetics, medicine, clothing, footwear, furniture, tourism, hospitality, logistics, banking, and stock market operations – but it is most commonly applied in the food and pharmaceutical industries, as well as in the production of cosmetics.

HALAL STANDARDS AND CERTIFICATION IN THE MEAT INDUSTRY

The strictest requirements of the Halal standard apply to the meat industry. For meat to be considered Halal, animals must be raised in accordance with their welfare, must be healthy and alive at the time of slaughter, and the act of slaughter must be performed by a person who is mentally stable and professionally trained. It is not permitted for the act to be carried out by someone under the influence of alcohol, nor by anyone who is not a Muslim, Christian, or Jew, as only they understand the importance of invoking the name of God during slaughter. Additionally, specific methods for restraining animals before slaughter are prescribed (Portal Kvalitet, n.d). Figure 1 shows the fundamental moral principles that form the basis of the halal meat industry, highlighting the interconnection between religious foundation, ethical slaughter procedures, transparency, and sustainability as key factors in ensuring ethically acceptable halal meat production (Rahman et al., 2024).



Figure 1 The Moral Foundations of Halal Meat Production (Rahman et al., 2024).

The list of approved Halal standards, schemes, and guidelines, including those related to meat, followed by Islamic countries is shown in Table 1.

A detailed understanding of the different forms of Halal certification – including certification of red meat and poultry, dried meat products, pharmaceutical and cosmetic preparations, as well as professional training in the field of Halal hospitality and the food industry – represents a key prerequisite for compliance with the standards of the growing global Halal market, both for consumers and business entities (Halal Food Council USA, 2024).

Halal certification is increasingly perceived as an indicator of food quality and safety, thereby enhancing its acceptance among various consumer groups. The principles of Halal diet promote the consumption of pure, nutritionally valuable food, moderation in eating, and a balanced dietary approach. Such practices not only contribute to the improvement of individual health but also influence global market trends, confirming the growing recognition of Halal certification as a standard of food quality and safety (Aung et al., 2025).

Modern consumers most often buy food that is prepackaged in stores, which makes proper product labeling crucial. Food labeling influences consumers' willingness to pay for certain product characteristics. Halal is an attribute that an individual cannot easily verify or confirm on their own. Therefore, consumers rely on competent authorities that check the Halal status and confirm it with appropriate certificates or labels. The most common way to verify the Halal status of food is a thorough check of the Halal certificate or label. In the case of meat, labels should include information about the place of birth, type of breeding and slaughter of the animal, as well as information on whether the slaughter was performed without anesthesia. When this information

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is not available, Muslim consumers often seek additional details, such as the origin of the seller, to confirm the Halal status of the product. Meat sold by a Muslim vendor is considered reliable even without an explicit Halal label (Meixner et al., 2018).

One of the methods for labeling Halal meat is shown in Figure 2.

Table 1. Halal standards schemes and guidelines (Halal Quality Control, 2024).

Halal Standards and Guidelines	HQC Schemes	Normative References
Organisation of Islamic Countries [OIC] OIC/SMIIC 1: 2019: General Requirements for Halal Foods OIC/SMIIC 4: 2018: General Requirements for Halal Cosmetics OIC/SMIIC 50-1:2022 Halal Pharmaceuticals - Part 1 - General Requirements OIC/SMIIC 23:2022 Feeding Stuffs for Halal Animals – General Requirements OIC/SMIIC 24: 2020: General Requirements for Food Additives OIC/SMIIC 17-1:2020: Halal Supply Chain Management Systems Part 1: Transportation OIC/SMIIC 17-2:2020: Halal Supply Chain Management Systems Part 2: Warehousing	HQC Halal Certification Scheme (HQC.S:2023) HQC Halal Assurance Program Scheme (HQC.S1:2023) HQC Animal Slaughtering and Awareness Scheme (HQC.S2:2023) HQC Service Providers Scheme (HQC.S3:2023) HQC Supervision Scheme (HQC.S4:2023) HQC Beauty and Personal Care Scheme (HQC.S5:2024)	International Standardization Organisation: ISO/IEC 17000: Vocabulary and general principles ISO/IEC 17065: Requirements for bodies certifying products, processes and services ISO/IEC 19011: Guidelines for auditing management systems ISO/IEC 17021: Requirements for bodies providing audit and certification of management systems Halal Authorities and Regulators: OIC/SMIIC 2:2019: Requirements for Bodies Providing Halal Certification OIC/SMIIC 57:2022: General Requirements for Operations of Bodies in Halal Inspections UAE.S 2055-2:2016: General Requirements for Halal Certification Bodies GSO 2055-2:2021: General Requirements for Halal Certification Bodies BPJPH Decree Number 78 of 2023: Halal Food and Beverage Certification Guidelines BCG Halal 1:2007: Brunei Darussalam Guidelines for Halal Certification



Figure 2. Halal label for meat (Nugraha et al., 2022).

CHALLENGES IN THE HALAL MEAT INDUSTRY

Industrial production of Halal red meat is carried out on a large scale and represents a globally widespread activity. The spiritual dimension of this meat is of key importance to consumers who adhere to Halal principles, with all aspects, including animal welfare during production, being crucial. However, numerous violations of animal welfare standards have been documented in both industrial and artisan Halal meat production. There is evidence of cruel treatment of animals during transport and preparation for slaughter, including long walks, physical abuse, deprivation of food and water, and transportation under unfavorable conditions. Additionally, animals are often treated inhumanely within slaughterhouses—without access to shade, in inadequate facilities, and with the use of force when being moved into slaughter areas. Despite clear Islamic and secular guidelines promoting zero tolerance for abuse, such unacceptable practices continue throughout the entire supply chain (Farouk, Pufpaff & Amir, 2016).

Research such as that conducted by Bux et al. (2022), although primarily focused on the broader context of Halal production, can be relevantly applied to the meat industry as well. Improving infrastructure to avoid contamination with non-Halal materials, along with an integrated role of management, are key aspects in the meat industry, especially given the strict requirements of Sharia law. Additionally, the application of information technologies and block-chain as tools to ensure traceability and authenticate products shows promise in the meat industry, where control over origin and slaughter conditions is central. Although the environmental impacts of block-chain technology have not yet been fully explored, its potential to improve sustainability, reduce chemical use, and enhance resource management—particularly in livestock production—opens opportunities for further research in the meat sector. Moreover, observed trends in waste reduction and creating value-added products from by-products can be successfully implemented in the meat industry through valorization of slaughter or processing residues. By utilizing digital supply chains, the meat industry can enhance transparency, extend product shelf life, and effectively respond to market challenges, thereby contributing to more sustainable and responsible Halal business practices.

One of the key applications of block-chain technology is smart contracts, which enable the automatic implementation and execution of conditions defined within the supply chain through programmed rules. These contracts operate as autonomous pieces of code that automatically confirm the fulfillment of previously agreed conditions between participants in the chain. In the context of the Halal supply chain, block-chain technology allows the digital representation of physical assets through unique digital identities, whose ownership and status can be managed and monitored via smart contracts that serve as the system's operational rules. For example, the process of issuing a digital Halal certificate can be automated so that the certificate is generated and issued immediately upon confirmation of payment for the certification process, thereby increasing efficiency, transparency, and security in managing Halal standards (Hidayati et al., 2023).

The Halal meat industry faces a range of challenges that affect system efficiency and consumer trust. One of the key issues is fragmented regulatory authority, as multiple government institutions apply different regulations, leading to overlap and inefficient oversight. This fragmentation complicates the resolution of disputes and slows institutional responses to sector incidents, such as scandals related to imported Halal meat. Inadequate border control further enables smuggling and the entry of unverified products into the market, jeopardizing the safety and authenticity of the Halal supply. At the same time, producers face rising costs for animal feed and meat processing, which are subject to market and currency fluctuations, increasing financial pressure on the sector. Managing the supply chain for Halal products is a particular challenge due to the length and complexity of international goods flows. Discrepancies between domestic and foreign regulations create risks of contamination and violation of Sharia principles. Additionally, counterfeit products and insufficient ingredient labeling remain significant problems, as limited inspection capacities hinder the detection of inauthentic or contaminated products. These challenges call for stronger regulatory mechanisms, improved inter-institutional cooperation, and modernization of quality control to preserve the credibility of the Halal system (Shahidan & Amid, 2023).

PRODUCTION OF HALAL MEAT IN SERBBIA

According to the latest population census from 2022, there are 13,011 Muslims and 153,801 Bosniaks living in the Republic of Serbia (Statistical Office of the Republic of Serbia, 2023). In recent years, there has been an increased influx of workers from Islamic countries, as well as growth in the number of tourists from those regions. These demographic trends point to the need for meat producers to align their production with Halal standards. The growing global demand for Halal meat offers domestic producers the opportunity to access new markets, which can contribute to the strengthening and expansion of the meat industry in Serbia.

The importance of implementing Halal standards in Serbia's meat industry is becoming increasingly pronounced, especially in the context of marketing products to markets with predominantly Muslim consumer populations. Halal certification requires meeting specific criteria related to animal welfare, hygiene conditions, supervision of the entire production process, as well as the exclusion of ingredients that are not compliant with Islamic regulations.

The application of these standards not only contributes to raising the level of quality, safety, and transparency in production but also enables compliance with modern sustainability and environmental protection requirements. Thus, in the domestic context, Halal certification is not limited solely to fulfilling religious conditions but is also established as a tool for enhancing competitiveness and responsibility in the meat processing sector. According to data from the Halal Agency of the Islamic Community of Serbia, during 2025, eight producers in the meat production and processing sector held valid Halal certificates (Table 2).

Table 2. List of meat producers and processors with valid Halal certification (Meshihat of the Islamic Community of Serbia, 2025).

Region	Producer (Place)
North Serbia (Vojvodina)	Industrija mesa Carnex (Vrbas)
	Perutnina Ptuj - Topiko d.o.o (Bačka Topola)
	Superior Foods d.o.o (Bačinci)
	Vukenović DOO (Boljevci)
Central Serbia	Yuhor (Jagodina)
	Laki Komerc d.o.o (Jagodina)
Western Serbia	Klanica Divci DOO (Divci)
	ŠEJN DOO (Šabac)

Meat and meat products produced in Serbia according to Halal standards are marked with the national Halal label (Figure 3).



Figure 3. The Moral Foundations of Halal Meat Production (Rahman et al., 2024).

By adopting these practices, producers can strengthen their competitive advantage through the development of sustainable strategies and environmental preservation. At the same time, consumers gain increased trust, the opportunity to express cultural diversity, and pathways open for intercultural cooperation between countries, religions, and traditions.

Limitations of Halal standard implementation in Serbia

Despite the growing interest in Halal certification, the implementation of these standards in Serbia's meat industry faces a number of limitations.

Key challenges include:

- Insufficient awareness among producers about the procedures and importance of Halal certification, which leads to lower motivation for implementing these standards. A limited number of accredited certification bodies, which affects the availability and speed of the certification process.
- Technical and organizational obstacles, especially in small and medium-sized facilities that lack adequate conditions for the physical and procedural separation of Halal and non-Halal production.
- Lack of specialized training and qualified personnel, which hinders the practical implementation of strict hygiene and Sharia standards.
- Incomplete legal regulation, given that Halal standards function as additional, non-mandatory standards outside the general food safety regulations.
- Weak promotion and visibility of Halal products in the domestic market, which may reduce their commercial viability for producers.

These limitations point to the need for systemic support to the meat industry, which should include producer education, institutional strengthening of certification bodies, as well as improvements in infrastructure and the legal framework, with the aim of enabling broader and more efficient implementation of Halal standards in this sector. In addition, it is essential to establish adequate mechanisms for institutional and financial support, including subsidies and technical assistance, in order to encourage the modernization of capacities in the meat industry and facilitate the integration of Halal standards into existing production processes.

Ecological aspects of Halal meat certification in Serbia

Halal meat certification in Serbia can significantly contribute to improving environmental standards in the meat production sector. The production methodologies applied within Halal standards are often aligned with principles of sustainability, resulting in a positive impact on the environment. Halal production processes are characterized by more efficient use of resources, particularly water and energy, which reduces the overall environmental footprint. The implementation of standardized procedures in Halal slaughterhouses and meat processing facilities in Serbia can contribute to optimizing the consumption of these key resources.

In addition, Halal certification involves the limitation or elimination of the use of synthetic chemicals such as pesticides, preservatives, and artificial colorants, thereby reducing pollution and enabling the production of more environmentally friendly products. Moreover, the growing use of eco-friendly packaging — including biodegradable and recyclable materials — contributes to reducing the negative impact on the environment, especially in the area of waste management.

The integration of these environmental principles into Serbia's meat industry enables the alignment of religious requirements with the demands of sustainable development, contributing to a responsible approach to environmental protection.

CONCLUSIONS

Although primarily defined through religious regulations, Halal certification in the context of modern food systems in Serbia has the potential to contribute to the improvement of environmental and production standards in the meat industry. Through strict requirements regarding hygiene, animal welfare, and process control, Halal practices can also be viewed as a framework for

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introducing more sustainable production methods. However, the implementation of Halal standards in Serbia faces a range of institutional, technical, and economic limitations that slow broader adoption and commercial viability of this approach. Insufficient producer awareness, a lack of accredited bodies, and the need for stronger legislative frameworks represent key challenges. Despite this, it is clear that Halal certification in Serbia not only opens opportunities for export and market diversification but also offers added value by contributing to principles of safe, ethical, and environmentally responsible food production. Further research and multi-sector cooperation can support better integration of Halal standards into the domestic meat production and control system, with potentially positive effects on industry sustainability and environmental protection.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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THE ROLE OF ECOLOGICAL FACTORS IN FREE-RANGE ANIMAL FARMING: IMPLICATIONS FOR FEASIBILITY AND ANIMAL WELFARE

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ABSTRACT

Ecological conditions play a crucial role in the success and sustainability of free-range animal farming. Factors such as climate, vegetation, water availability, and terrain directly influence not only the feasibility of managing animals in open or semi-open systems but also the quality of their welfare. In restrictive environments like cages or small enclosures, animal welfare is often compromised due to lack of space, limited stimulation, and inability to express natural behaviors. Although such systems allow for easier management and safety, they rarely meet the animals' biological needs. In contrast, free-range and semi-free systems offer animals access to more natural habitats, promoting physical health, mental stimulation, and natural behaviors such as grazing, roaming, and social interaction. However, these systems require careful ecological planning, as poor environmental conditions can lead to health issues, resource scarcity, and increased human–animal conflict. Ensuring animal welfare in free-range farming depends on aligning management practices with environmental conditions and species-specific needs. Proper oversight, sufficient resources, and ecological compatibility are essential to create systems that are both ethically responsible and practically viable. Ultimately, ecological factors are foundational to designing humane, functional, and sustainable free-range animal farming systems.

Keywords: ecological conditions, free-range animal farming, animal welfare, feasibility, natural behaviors.

INTRODUCTION

Animal welfare encompasses the physical and mental state of an animal in relation to the conditions in which it lives and dies (Fraser, 2008). In modern production systems, where the emphasis is often on cost-effectiveness and productivity, animal welfare may be compromised. However, numerous scientific findings indicate that there is a clear link between animal welfare, health and performance, as well as the quality of their final product (Broom, 2011).

Animal welfare is one of the key issues in modern livestock production, veterinary practice, and the ethical relationship of society towards animals. This paper addresses the concept of animal welfare, its ethical, economic, and legal aspects, as well as its significance for animal health, the quality of products of animal origin, and the sustainability of agriculture. Based on a review of relevant references, it is concluded that ensuring a high level of welfare is of essential importance not only for animals, but also for humans and the broader environment. Animal welfare encompasses the quality of life and a harmonious relationship between the animal and its environment, and it is becoming an increasingly important topic in conventional production, as well as a key and indispensable element in organic livestock farming.

The aim of this paper is to highlight the importance of welfare from multiple aspects and to point out the need for its improvement in practice.

THE IMPORTANCE OF ANIMAL WELFARE

In modern production systems, where the emphasis is often on cost-effectiveness and productivity, animal welfare may be compromised. Animal welfare encompasses the physical and mental state of an animal in relation to the conditions in which it lives and dies (Fraser, 2008). However, numerous scientific findings indicate that there is a clear link between animal welfare, health and performance, as well as the quality of the final product (Broom, 2011).

The aim of this paper is to point out the key role that welfare plays in modern livestock production and sustainable development. Special emphasis is placed on identifying the existing challenges in implementing legal and professional standards in practice, as well as on the need for a systematic improvement of the approach to animal welfare.

Definition and components of animal welfare

According to the World Organization for Animal Health (OIE, 2023), animal welfare encompasses five freedoms:

- Freedom from hunger and thirst
- Freedom from discomfort
- Freedom from pain, injury, and disease
- Freedom to express natural behaviour
- Freedom from fear and distress

These freedoms form the basis for assessing and improving the conditions in which animals are kept in households, farms, transport, and slaughterhouses (Manteca et al., 2021). This definition is known as the Five Freedoms concept; they are species-specific, apply to all animals, and are valid in all situations.

Ethical aspects of welfare

Caring for animal welfare represents a fundamental expression of human ethical responsibility towards beings capable of feeling pain, fear, pleasure, and other emotional states. Ethical approaches to animals have developed over the centuries, and modern philosophical reflections have significantly contributed to understanding and promoting the moral duty towards animals. Philosophers such as Peter Singer (1975) and Tom Regan (1983) emphasised the moral obligation of humans to minimise animal suffering. They advocated minimising suffering and maximising the welfare of all sentient beings, which has had a revolutionary impact on animal rights and protection movements worldwide. These philosophical foundations form the basis of modern animal protection legislation in many countries, including international protocols and recommendations such as those issued by the World Organization for Animal Health (OIE). In legislation, ethical aspects are reflected in regulations requiring humane conditions for keeping, transporting, and handling animals, with the aim of reducing unnecessary suffering and improving quality of life. The preservation and enhancement of animal welfare, therefore, represent not only a matter of legislation and science, but also a profound ethical imperative of modern society, which strives to establish a harmonious relationship with the animal world and nature as a whole.

Welfare and production

Numerous studies show that poor housing conditions lead to increased disease incidence, reduced fertility, and slower growth in animals (Grandin, 2015). On the other hand, improving welfare can enhance performance, the quality of meat, milk, and eggs, as well as the economic results on farms (Hemsworth & Coleman, 2010). For example, cows that have access to pasture and lying areas with soft bedding or flooring show higher daily milk yields (Fregonesi et al., 2007).

Stadig et al. (2017) point out that access to outdoor runs can positively impact the welfare of broiler chickens, as it allows them to stay in a more natural environment and provides more opportunities to express innate behaviors compared to indoor poultry housing systems. Additionally, increased space and the presence of enrichment elements in the system where they are kept can contribute to better leg health and reduced fearfulness in poultry. However, in

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practice, outdoor runs are often used only to a limited extent. The key reasons for this are likely the lack of shelter and unfavorable weather conditions.

Numerous studies have analyzed the use of outdoor runs on free-range layer farms, finding that the percentage of poultry using the run at any given time rarely exceeds 50% of the total flock and sometimes is below 10%. Defining the optimal level of run use is challenging due to the lack of detailed knowledge about the duration of birds' time spent outdoors under ideal conditions (Pettersson, Freire, & Nicol, 2016). Although poultry in free-range systems have access to outdoor areas, not all birds use them to the same extent (Singh & Cowieson, 2013).

It has been proven that factors such as current weather conditions, flock size, and availability of shelter in the outdoor run significantly affect the percentage of run usage. Additional elements, including the design of entry/exit openings (pop-holes), internal and external stocking density, as well as the overall concept of the housing system, can also have an impact, although their effects are not yet sufficiently researched or clearly defined. Therefore, further scientific analysis is needed to better understand their relevance. Factors influencing the distribution of birds within the outdoor run itself are also being considered (Pettersson et al., 2016).

Animal welfare primarily represents their physical health, where the production results of animals are far better when welfare is achieved — meaning they are provided with enough movement, social interaction since they are social beings, and access to quality, well-managed pasture.

A group of authors studied the literature with the aim of gathering information on the sustainability of free-range pig farming systems, including management, performance, and pig health in these systems (Miao, Glatz, & Ru, 2004). Modern free-range systems require simple, portable, and flexible facilities with low-cost fencing. Local pig genotypes adapted to external conditions are generally more suitable for free-range systems. Free-range farms should be located in areas with low rainfall, while the plots should be relatively flat with a shallow topsoil layer, free of sharp stones that could cause leg injuries. Shelters or huts are essential to protect pigs from direct exposure to sunlight and heat stress, especially when there is no natural shade such as trees or other structures. Access to mud wallows satisfies their behavioral needs and helps overcome the negative effects of high temperatures on feed intake.

Miao et al. (2004) state that with proper management, pig production in free-range systems can be comparable to that of pigs kept indoors, although litter growth rates vary depending on the season. Piglets raised indoors grow faster during the cold months compared to those raised outdoors. Pigs raised outdoors exhibit calmer behavior. Aggressive interactions during feeding are less frequent than in indoor pigs, while sows outdoors are more active. Diseases can be partially controlled by pasture management. Frequent rotation of plots is necessary, although many farmers keep pigs in the same area longer before moving them. Plants that can be locally grown and used as part of the regular diet are likely to be acceptable to farmers, especially organic producers.

However, one of the main public concerns regarding free-range pig systems is their environmental impact. In the past, pigs were kept on the same plots with large numbers of animals in a small area, which led to vegetation damage, excessive soil nutrient saturation, nitrate leaching, and gas emissions. To avoid this, outdoor pigs should be integrated into soil and pasture management systems, and the number of animals adjusted to the amount of available feed, with herd mobility (Miao et al., 2004).

Kvesić (2016), in her research on pig behavior in outdoor and indoor housing systems, concludes that pigs kept outdoors have complete freedom in their feeding. Pigs root in the soil, satisfying their strong exploratory behavior, and find food present in pastures or forests to feed on. On the other hand, in indoor systems, pigs have more readily available food and do not display natural behaviors associated with foraging outdoors, which leads to frequent aggressive interactions due to a lack of space for feeding.

Abnormal behaviors are those not typical in natural conditions and most commonly occur in indoor housing systems. These include tail and ear biting, cannibalism, and aggression, which are most pronounced due to overcrowding, poor environmental conditions, inadequate nutrition, and

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similar factors. One of the major problems in modern pig housing systems is the appearance of stereotypical behaviors, which are a direct indicator of poor welfare (Kvesić, 2016).

Regarding mental stimulation, it is important to allow animals to express natural species-specific behaviors, which in turn ensures high animal welfare by providing space for normal body postures, especially of the legs, wing spreading, dust bathing, and more, as well as for feeding and necessary rest.

Supporting this, Rodríguez-Estévez et al. (2010) found that pigs in free-range systems divided into smaller subgroups during grazing, maintaining these divisions even during daytime rest, while at night they regrouped into a single unit and behaved as one cohesive herd. In this way, large groups formed in intensive farms could be considered natural, provided that overcrowding does not occur, which would help avoid stress (Rodríguez-Estévez et al., 2010).

Social interaction, contact with other members of the same species, and a stimulating environment are necessary to prevent boredom. When bored, animals may exhibit unwanted behaviors that disturb the peace on the farm—especially in conventional production systems or on outdoor runs—disrupting welfare as well as the quantity and quality of the products obtained. Common behavioral disorders include food overturning and scattering, tongue playing, bar biting, object licking, sucking on other animals, tail biting in pigs, feather pecking in poultry, aggression, cannibalism, and more.

Petersen, Recén, and Vestergaard (1990) studied the behavior of sows and piglets during farrowing in free-range conditions and concluded that, despite domestication, pigs are still well adapted behaviorally to successfully cope with the challenges of farrowing in free-range systems.

In organic production, animals must be raised in accordance with their basic needs — that is, in a way that allows them to express most of their normal behaviors (both innate and learned) while respecting fundamental principles of welfare and protection.

Recognizing the importance of behavior, welfare, and animal protection, organic production, as an alternative to conventional farming, is precisely aligned with the natural needs of animals (Petrović et al., 2018). Good health status should always be a priority.

Animals have the ability to respond to changes in the external environment (so-called stressors). If an animal is unable to adapt to these changes, stress occurs. Stress usually has a negative impact on animals and their productivity and can be measured by changes in blood parameters, hormonal status, and behavior. Prolonged stress leads to suffering.

Proper management, sufficient resources, and ecological compatibility are key to creating systems that are both ethically responsible and practically sustainable. Ultimately, environmental factors form the foundation for designing humane, functional, and sustainable free-range animal farming systems.

Environmental Factors as Determinants of Animal Welfare and Successful Rearing

Environmental factors play a crucial role in shaping the conditions of animal housing, behavior, and productivity, especially in extensive and free-range farming systems. Climate, vegetation, water availability, and terrain characteristics directly affect the quality of life and welfare of animals, as well as the efficiency of livestock management. Adapting farming systems to the specifics of the local ecosystem forms the foundation for a sustainable and ethically acceptable livestock approach.

Climate – Climatic conditions, including temperature, precipitation, wind, and seasonal changes, are crucial in determining the availability of natural food throughout the year, as well as the conditions for animals to stay outdoors. Extreme temperatures (cold or heat), high humidity, or frequent changes in weather can negatively affect the health, behavior, and productivity of animals, requiring adapted protective measures—such as shelters, natural or artificial shade, and supplemental feeding during periods of scarcity.

Vegetation – Natural vegetation provides essential resources for feeding, shelter from adverse weather, and space for free movement and expression of natural behavior. The biodiversity and structure of plant cover directly affect the quality of nutrition, as well as protection from stress and

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parasites. Preserved vegetation also serves an ecological function by preventing erosion, maintaining soil quality, and regulating micro climatic conditions in pastures.

Water – The availability of clean and fresh water is a fundamental prerequisite for animal survival, proper physiological functioning, and hygiene maintenance. In free-range farming, water sources must be easily accessible, safe, and reliable throughout the year. Lack of water, whether due to drought or difficult terrain access, can lead to serious health issues, reduced production performance, and compromised animal welfare.

Terrain – The topography of the land affects pasture accessibility, the ability to control animal movement, and overall farm management. Steep, slippery, or overly rocky terrain can pose physical obstacles and injury risks, while flat or gently sloping land allows easier management, better distribution of food and water, and safer animal movement. Additionally, soil characteristics influence water absorption, vegetation growth, and habitat formation.

Environmental factors form the foundation of every successful and sustainable livestock production system. Understanding and respecting local ecosystem characteristics is essential for planning farming practices that ensure high welfare standards, minimal negative environmental impact, and long-term economic sustainability.

Legal framework

In the European Union, animal welfare is regulated by a series of legally binding regulations, including directives and regulations, among which one of the key pieces of legislation is Council Directive 98/58/EC on the protection of animals kept for farming purposes. These regulations set minimum standards for housing, feeding, care, and health protection of animals, with an emphasis on preventing suffering and ensuring natural behavior.

In the Republic of Serbia, the legal framework for animal welfare protection is defined by the Animal Welfare Act (Official Gazette of RS, No. 41/2009), which clearly stipulates the obligations of animal owners and keepers, as well as the authority of inspection bodies to ensure conditions that prevent pain, suffering, and stress in animals.

However, despite the existence of appropriate legal regulations, significant deviations in their implementation often occur in practice. These deviations most commonly arise from a lack of expert knowledge and education, limited financial resources, as well as inadequate or inconsistent supervision by the relevant authorities. Consequently, the actual conditions in which animals live frequently fail to meet the prescribed standards, highlighting the need for improved institutional support, education, and enforcement of legal measures in the field of animal welfare.

Routine welfare assessment is important for the application of animal welfare laws and regulations in practice, which in many countries around the world govern the provision of welfare in areas such as farming technology, housing and accommodation, transport, and slaughter of animals (Hristov & Relić, 2009).

Welfare assessment systems are based on the fact that welfare can be measured (Broom, 1991), and welfare indicators include parameters that can be qualitatively and quantitatively evaluated (Hristov et al., 2006).

Assessment is particularly important under different housing and accommodation conditions, as well as for various species and categories of farm animals, taking into account their specific characteristics (Fregonesi, 1999).

Despite growing social and professional awareness of the importance of animal welfare, its consistent implementation in livestock practice still faces numerous challenges. One of the fundamental problems is the discrepancy between scientifically based recommendations and the real conditions in which production takes place. Although science provides clear guidelines on optimal housing, nutrition, health care, and animals' need to express normal—natural—behavior, their implementation is often hindered by limited resources, insufficient technical support, or structural barriers at the production system level.

Economic pressures on farmers, especially in intensive production systems, pose an additional obstacle to achieving high welfare standards. Maintaining better conditions for animals often requires greater investment in infrastructure, labor, and veterinary care, which can be

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discouraging under conditions of low purchase prices and market instability. In this context, welfare is often perceived as a cost rather than an investment that can, in the long term, contribute to greater productivity, product quality, and market competitiveness.

Besides economic factors, a significant challenge is insufficient education and low motivation among employees who work directly with animals. A lack of expert knowledge about animals' behavioral needs and the ethical aspects of husbandry often leads to inadequate care, stress, and reduced performance. For this reason, it is essential to implement continuous professional development programs, mandatory training, and certification for farmers and personnel in the livestock sector.

To overcome these challenges, a comprehensive and integrated strategy is needed that unites multiple sectors — from education and science, through agricultural policy, to market mechanisms. Key components of such a strategy include:

- *Education and empowerment of producers* through training, access to advisory services, and dissemination of scientific knowledge;
- *Implementation of legal and voluntary standards* with clear guidelines and measurable welfare indicators;
- *Effective inspection oversight* with consistent enforcement of regulations and sanctioning of violations;
- *Economic incentives and support*, including higher purchase prices for products meeting high welfare standards, subsidies for improving housing conditions, and access to markets with special requirements (e.g., the EU market, certified organic production, Halal and Kosher production and certification, etc.).

Additionally, *consumer awareness* plays an important role, increasingly shaping demands regarding product quality and production conditions. Educating consumers and transparent product labeling based on welfare criteria can create additional market pressures that motivate producers to make changes.

Therefore, animal welfare cannot be viewed in isolation but as part of a broader system where education, legislation, economics, and ethics are interconnected. Only through a coordinated approach is it possible to ensure lasting improvements in practice and create production systems that are ethically acceptable, economically sustainable, and socially responsible.

CHALLENGES AND POTENTIAL SOLUTIONS TO MANAGING ECOLOGICAL FACTORS IN ANIMAL FARMING

Livestock management in accordance with ecological conditions faces a range of challenges that can negatively impact animal welfare and system sustainability. Identifying these issues and applying appropriate, scientifically based solutions are crucial for improving production performance and protecting animals.

Drought as a Limiting Factor and Irrigation Systems — One of the most common and damaging climatic challenges is drought, which directly affects the availability of food and water. According to the University of Saskatchewan – Livestock and Forage Centre of Excellence (2023 and 2024), prolonged periods without precipitation reduce forage yields on pastures, making natural feeding difficult for animals and threatening their physiological stability. Drought can also cause soil degradation and reduce biodiversity, further damaging the ecosystem. An effective solution to this problem is the implementation of irrigation systems, which help maintain optimal soil moisture levels, increase pasture yields and quality, and thus improve food availability. Modern irrigation methods, such as drip irrigation, offer efficient and economical ways to conserve resources and adapt production to climatic conditions. Managing pastures during drought periods requires adjusting grazing regimes and protecting vegetation to preserve soil productivity and animal health. Rotational grazing, the use of alternative feed sources, and alleviating pressure on plant biomass during drought are recommended practices (Mississippi State University Extension Service, 2023). Deficit irrigation has proven to be an effective approach under conditions of limited water availability. This practice allows significant resource conservation without seriously

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affecting pasture yields, which is crucial in drought-prone climates (Utah State University Extension, 2023).

Lack of Vegetation and Sustainable Pasture Management — Vegetation degradation, caused by overgrazing, adverse climatic conditions, or human activities, presents a serious challenge to the sustainability of livestock systems. Insufficient plant cover reduces the potential for natural feeding, disrupts microclimatic conditions, and can lead to soil erosion. Sustainable pasture management involves practices such as rotational grazing, mowing vegetation in accordance with natural cycles, restoring degraded areas, and preserving biodiversity. These measures enable the long-term conservation of pastures as a fundamental resource in extensive livestock farming, while simultaneously increasing their productivity and resilience to climatic stresses, according to research from leading global universities (Bastani, 2023; Hou et al., 2024). Milazzo et al. (2023) note that grasslands are at risk of degradation due to unsustainable management practices and ongoing climate change. A sustainable approach to pasture management contributes to providing ecosystem services and strengthening the resilience of grassland systems to anthropogenic changes.

Predator Threat and Protective Measures — The presence of predators can have a significant negative impact on the safety and welfare of domestic animals, causing stress, injuries, and even losses (Linnell et al., 2008; Gehring et al., 2011). Traditional protection methods, such as physical fencing, are not always sufficient or economically viable, especially on large or inaccessible pastures. Modern approaches include a combination of protective fencing adapted to local conditions, the use of electric or other innovative systems, as well as continuous monitoring through technological solutions like cameras and sensors. Additionally, the involvement of shepherds and livestock guardian dogs can greatly contribute to preventing predator attacks. Together, these measures enable effective animal protection, reduce losses, and improve overall welfare (Van Eeden et al., 2018).

Plokhikh et al. (2023) developed a methodology for ecological auditing and impact assessment of pasture agro-landscapes, using a landscape-ecological and indicator-based approach, aimed at improving sustainable land management in central Kazakhstan. Reliable ecological audits and environmental impact assessments are crucial for the efficient use of pastures and ensuring the production of high-quality livestock products.

Successfully overcoming ecological challenges in livestock farming requires an integrated approach that combines technical solutions, sustainable management practices, and the application of innovative technologies. This approach can achieve a balance between conserving natural resources, protecting animal welfare, and ensuring the economic sustainability of production.

CONCLUSIONS

Animal welfare is a multidisciplinary concept encompassing ethical, economic, health, and sustainability aspects, and it plays an increasingly important role in modern livestock production systems. Improving welfare not only benefits the physiological and psychological condition of animals but also positively impacts the quality and safety of animal-derived products, enhances consumer trust, and strengthens the market position and reputation of producers.

Numerous scientific studies confirm that systems based on welfare principles—such as providing adequate space, access to pasture, environmental enrichment, and the expression of natural behaviors—have a positive effect on animal health, productivity, and resilience. Accordingly, the development of animal welfare protection policies must be accompanied by continuous investment in farmer education, technological advancement, and strengthening institutional support to ensure consistent implementation of science-based practices.

In free-range or extensive farming systems, the successful implementation of high welfare standards depends on ecological compatibility, quality management, and understanding the complex relationships between animals, their environment, and the production system. Only under conditions that meet the biological needs of animals and allow for stable production can such an approach be both ethically justified and economically sustainable.

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In this context, animal welfare should not be viewed solely as a normative or moral obligation, but as a key element of sustainable livestock development and the long-term stability of the food system.

Through education, technical and technological innovations, better regulatory enforcement, and broader social awareness, this work aims to contribute to understanding animal welfare not only as a humane responsibility but also as a factor that directly impacts product quality, human health, environmental protection, and the sustainability of the entire agroecosystem.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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REDUCING GHG EMISSIONS THROUGH IMPROVED WASTE MANAGEMENT: CASE STUDY OF THE CITY OF PRNJAVOR

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ABSTRACT

Waste management is becoming an increasingly important factor in the context of climate change, particularly due to methane emissions from landfills, which have a significantly stronger warming effect than carbon dioxide. The City of Prnjavor, facing challenges related to the growth of municipal waste and limited infrastructure, represents a representative example of a local community in transition toward a more sustainable waste management system. The aim of this research is to assess greenhouse gas (GHG) emissions from the waste sector and identify optimal strategies for their reduction.

The methodology is based on the IPCC Tier 1 approach for GHG emission estimation, applied to three waste management scenarios: full landfilling, partial recycling, and a combination of recycling and composting. The analysis includes emissions from waste collection, transport, and final treatment, as well as avoided emissions resulting from the processing of recyclable and biodegradable fractions.

Results show that the scenario combining recycling and composting can reduce total GHG emissions by 37% compared to the baseline scenario.

The conclusions suggest that transitioning to selective waste collection and treatment, along with strengthening institutional capacities, has the potential to enable efficient emission reductions and improve the waste management system, without the need for major infrastructure investments.

Keywords: GHG emissions, waste management, IPCC.

INTRODUCTION

The growing development of industry has provided numerous advantages for humanity, such as a higher standard of living, technological progress, and access to various products and energy sources. However, the negative effects of industrialization have become increasingly evident, particularly through the rising pollution of water, air, and soil. Population growth and increased consumption of food and various goods have led to a continuous rise in the amount of waste generated. If waste is not properly collected and managed, it can cause serious environmental and public health consequences. In order to mitigate the negative impacts of waste, it is essential to properly organize its collection, transportation, and final disposal.

Waste management is today one of the key societal issues, primarily due to significant environmental and climate-related challenges. The waste management sector is a major global source (GHG) emissions, which directly contribute to climate change. According to the Intergovernmental Panel on Climate Change (IPCC), the waste sector is responsible for approximately 3–5% of global anthropogenic GHG emissions, with the majority of these emissions stemming from methane (CH₄), a gas generated through the anaerobic decomposition of biodegradable waste in landfills (IPCC, 2014). Methane has about 28 times greater global warming potential than carbon dioxide (CO₂) over a 100-year period, making it a priority target in efforts to combat climate change (IPCC, 2014).

Bosnia and Herzegovina, like many other countries, faces challenges in establishing an efficient and sustainable waste management system. The United Nations Environment Programme (UNEP) states that proper waste management—including separation, recycling, composting, and

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reducing landfilling, can be an important factor in reducing GHG emissions (UNEP, 2010). Sustainable waste management involves minimizing waste generation, recycling, treatment, energy recovery, and the safe disposal of waste that cannot be reused. The Republic of Srpska has developed a regional municipal waste management system to ensure controlled and safe disposal of waste (MPUGE RS, 2020).

The City of Prnjavor is part of the Banja Luka region, which utilizes the Ramići regional sanitary landfill, located 54 km from the city and managed by the public utility company JP "DEP-OT" Banja Luka. PU "DEP-OT" was established in 2003 through a joint initiative of the City of Banja Luka and surrounding municipalities, with the aim of centralizing waste disposal at a single location (LWMP, 2021).

Operational waste collection in Prnjavor is carried out by the public utility company "Park" a.d. Prnjavor. The system covers approximately 30 local communities, while two remain outside the organized collection system, indicating partial service coverage (LWMP, 2021). In urban areas, waste is collected daily, in suburban areas weekly, and in rural parts every two weeks. In addition to regular waste collection, the company also provides waste collection upon request, by placing containers with a capacity of 7 m³ and 1.1 m³ (KP "Park" a.d., 2024).

In the city area, there are so-called "green islands" with six sets of containers for PET, metal, glass, and paper, as well as an additional 14 metal mesh containers for PVC packaging. However, the total number of containers for secondary raw materials and hazardous fractions is insufficient for optimal system functionality (KP "Park" a.d., 2024).

On average, around 25 tons of waste are transported daily from the area of Prnjavor to the regional landfill. The main problems encountered during collection include inadequate waste bins, improperly parked vehicles, and incorrectly disposed waste. Currently, there are no identified illegal dumpsites, but there is a persistent issue of overflowing containers, which requires an increase in their number, especially in the city center (KP "Park" a.d., 2024).

The company's vehicle fleet consists mainly of older diesel trucks, which have relatively high gas emissions. The utility company plans to construct a transfer station, but there is currently no designated location or financial means for its construction (KP "Park" a.d., 2024).

The Local Waste Management Plan envisions the introduction of primary waste separation in households, institutions, and businesses using two color-coded bins for dry recyclable and wet non-recyclable waste. The waste would be transported to separation lines for further processing and recovery. Additionally, it foresees intensified collection of biodegradable waste during peak periods, such as autumn (leaves, branches). For bulky waste and special fractions, the plan proposes the establishment of a sorting center and seasonal collection. However, these recommendations have not yet been implemented, which slows down the establishment of a functional and sustainable system (LWMP, 2021).

In the Republic of Srpska, five regional landfills are operational: Banja Luka, Bijeljina, Zvornik, Prijedor, and Dobož, which are designated for the disposal of municipal and non-hazardous industrial waste. The landfill in Ramići is the largest among them, receiving waste from eight local communities, including Prnjavor, and covering an area with approximately 357,595 inhabitants. The landfill is equipped with the necessary infrastructure for controlled waste management, including systems for leachate control and landfill gas flaring (MPUGE RS, 2020).

The City of Prnjavor is facing a continuous daily increase in the amount of generated waste, while the existing waste management system does not fully meet ecological and climate-related goals. The aim of this paper is to provide a quantitative assessment of GHG emissions resulting from waste management in Prnjavor, using internationally recognized IPCC methodologies. Three waste management scenarios were modeled: landfilling, partial recycling, and a combination of recycling with composting. The analysis includes emissions from waste collection, transportation, and disposal, as well as avoided emissions resulting from recycling and composting activities. The results of this analysis are intended to serve as a basis for improving the current waste management system in Prnjavor and for achieving both local and national environmental objectives.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 through a joint initiative of the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The main reason for its creation was the growing concern over the rising concentration of GHG in the atmosphere and their impact on the planet's climate (IPCC, 2014). During the 1980s, numerous scientific studies indicated alarming trends such as the increase in average global temperatures, rising sea levels, and more frequent extreme weather events (WMO & UNEP, 1988; IPCC, 2007). In response to these challenges, the IPCC was founded as a scientific body that does not conduct its own research, but rather synthesizes existing literature and provides objective information on climate change to governments and policymakers (IPCC, 2014).

The primary role of the IPCC is to develop scientifically based methodologies for quantifying GHG emissions from various sectors, including the waste sector. The methodologies developed by the IPCC are known as emission inventory guidelines and are categorized into three tiers (Tier 1, Tier 2, and Tier 3), depending on data availability and the required level of detail for assessment (IPCC, 2006; IPCC, 2019a). The Tier 1 methodology is the most basic approach, relying on standardized emission factors and simple formulas, and is recommended for use in developing countries and communities with limited access to detailed data (IPCC, 2006).

Municipal waste management is a significant source of GHG emissions, as every stage of the system, from collection and transportation to final disposal, contributes to overall emissions. The most important GHGs generated in this sector are methane (CH₄), carbon dioxide (CO₂), and nitrous oxide (N₂O). The largest share of these emissions originates from sanitary landfills, where biodegradable waste decomposes anaerobically, producing methane (Bjelić et al., 2023). According to Gautam and Agrawal (2021), the waste sector contributes approximately 5% of total global GHG emissions, with a particularly high percentage coming from landfills that do not have systems in place for the collection and treatment of landfill gas.

A significant potential for reducing GHG emissions lies in improving the operation of sanitary landfills, primarily through the installation of systems for methane collection and flaring. Such systems can reduce emissions by up to 70% compared to the initial state. Additionally, the integration of separate waste collection and recycling further contributes to emission reductions through so-called "avoided emissions," which result from replacing primary raw materials with secondary resources (Bjelić et al., 2023). Turner et al. (2015) emphasize that recycling materials such as plastic, metal, and glass has particularly high potential for emission reduction.

Composting organic waste also contributes to lowering GHG emissions, as it prevents anaerobic decomposition and methane formation in landfills while replacing chemical fertilizers. According to Thanh, Yabar, and Higano (2015), one ton of compost can significantly reduce the need for mineral fertilizers and thus indirectly lower emissions associated with their production.

Emissions from waste transport represent an important component of the total emissions in the waste management sector. Older vehicles, diesel fuel, a high number of daily routes, and non-optimized logistics increase emissions of CO₂, NO_x, and particulate matter. Fleet modernization, route optimization, and the use of cleaner fuels can reduce waste transport emissions by up to 18% (Bjelić et al., 2022).

The reduction of emissions from the waste sector has been recognized as an important objective in international climate commitments, such as the Paris Agreement and the Nationally Determined Contributions (NDCs). Therefore, the implementation of effective waste management measures, such as separate waste collection, recycling, composting, and landfill gas management is recommended not only for reducing emissions, but also for strengthening the capacity of local communities to address climate change (UN Environment, 2018; IPCC, 2019a; World Bank, 2018). These activities simultaneously support socio-economic development, employment, and more efficient use of local resources, thereby contributing to the overall sustainable development of communities (King & Gutberlet, 2013; Ludwig et al., 2012).

The subject of this paper is the calculation of GHG emissions from the municipal solid waste management sector in the area of the City of Prnjavor, using the IPCC Tier 1 methodology. The analyzed scenarios include landfilling, partial recycling, and a combination of recycling and composting, with quantified emissions from landfilling, waste collection, transport, as well as

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avoided emissions due to recycling and composting. The aim of this study is to identify, based on the conducted analysis, the measures that can improve the existing waste management system, reduce its negative environmental impact, and contribute to achieving sustainable and climate-resilient objectives, in accordance with local and national strategic documents. The paper also aims to provide useful insights for decision-makers and local government units, and to serve as a starting point for developing improved local waste management plan.

MATERIAL AND METHODS OF WORK

As part of the analysis, the impact of different municipal solid waste management scenarios on GHG emissions in Prnjavor was assessed for a total annual waste quantity of 6507 tonnes. The morphological composition of the waste was based on the results of a study conducted at the “Ramići” landfill within the framework of the EIB project (EIB, 2024). Recyclable materials make up approximately 49,6% of the total waste, while the organic component accounts for 17,2%, making them key factors in the assessment of GHG emissions.

The objective of this study is to quantify emissions for four different scenarios and identify measures for their reduction.

Scenario 1 (Baseline scenario) reflects the current state, with no organized recycling or composting, where all waste is disposed of in the landfill without any treatment. Emissions result from the anaerobic decomposition of organic waste and the transport of waste to the landfill. This scenario serves as a reference base for comparison (LWMP, 2021).

Scenario 1a (Transport improvement) represents a technical enhancement through the construction of a transfer station and the introduction of a semi-trailer for waste transport, optimizing logistics, reducing fuel consumption, operational costs, and emissions from transportation. This scenario has been proposed in the Local Waste Management Plan as a priority measure (LWMP, 2021).

Scenario 2 (Partial recycling) involves establishing a basic system for source separation of recyclable waste, in which 10% of the total waste volume is diverted from disposal. The separated materials are recycled, thereby reducing landfill volumes and emissions through avoided production of primary raw materials (LWMP, 2021).

Scenario 3 (Integrated system with recycling and composting) represents the most advanced approach, combining recycling (15%) and composting (10%) of biodegradable waste from kitchens and gardens. A portion of the waste is composted centrally, while another portion is processed through household composters. This scenario significantly reduces the amount of landfilled waste, eliminates part of the transport demand, and aligns most closely with sustainable waste management principles outlined in the strategic documents of the Republic of Srpska (MPUGE RS, 2020; SEI, 2022).

In this paper, GHG emissions from municipal waste disposal were estimated using the basic approach (IPCC Tier 1), recommended for emission inventory development when detailed local data on waste composition and decomposition dynamics are unavailable (IPCC, 2019b). The Tier 1 methodology employs internationally accepted default values derived from global research, enabling a practical estimation of emissions based on fundamental information such as waste quantity, composition, disposal method, and the presence of emission control systems.

The methodology assumes that methane emissions occur in the same year the waste is landfilled, without detailed modeling of the temporal dynamics of decomposition. The estimation is performed using a standardized mathematical formula prescribed by the IPCC, which takes into account: the quantity of waste, the proportion of biodegradable material in the waste, the type of landfill, and the presence of methane capture systems and oxidation in the landfill's upper layers (IPCC, 2019b).

$$\text{CH}_4 \text{ emissions (Gg/y)} = [(\text{MSW}_T \cdot \text{MSW}_F \cdot L_0) - R](1 - \text{OX})$$

Where is:

MSW_T – total generated municipal solid waste (Gg/year)

Bijelić, D. et al. (2025). GHG emissions through improved waste management; case study of the city of Prnjavor. *STED Conference 14(2)*, 29-37.

MSW_F – fraction of generated waste disposed to landfill

L_0 – methane generation potential

R - fraction of methane recovered (Gg/year)

OX – oxidation factor

All parameters that are not locally known were taken from IPCC recommendations. The DOC content is calculated based on the composition of the waste (IPCC, 2019b):

$$DOC = 0,4 \times A + 0,17 \times B + 0,15 \times C + 0,3 \times D$$

Where is:

A – share of paper and textiles,

B – share of garden and green waste,

C – share of kitchen waste,

D – share of wood waste.

In addition to emissions from the landfill, emissions from diesel fuel consumption during waste collection and transport were also calculated. For avoided emissions, emission factors were used for individual recycling streams (paper, plastic, metals, glass) and composting (Vogt et al., 2023).

RESULTS AND DISCUSSION

The results obtained using the IPCC Tier 1 methodology enabled a quantitative assessment of GHG emissions from the municipal waste sector in the city of Prnjavor for the defined waste management scenarios. The analysis includes emissions from landfilled waste, as well as emissions resulting from waste collection and transport activities. All data were analyzed for a single calendar year, using reference values recommended by the IPCC (2006; 2019b). The results of the GHG emission estimates by analyzed scenarios and their components are presented in Figure 1.

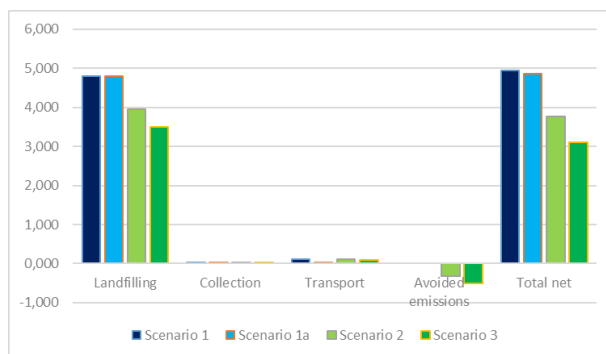


Figure 1. Comparison of GHG emission components by MWM scenarios.

In Scenario 1, where all waste (6507 tonnes) is landfilled without prior treatment, methane emissions amount to 0,171 Gg (4,791 Gg CO₂eq), while emissions from collection and transport reach 0,036 Gg and 0,117 Gg CO₂eq, respectively. The total net emissions amount to 4,944 Gg CO₂eq, making this scenario the most unfavourable in terms of climate impact.

Scenario 1a involves the improvement of waste transport logistics through the introduction of a transfer station. Emissions from landfilling and collection remain the same, while transport emissions decrease to 0,037 Gg CO₂eq. The total net emissions are reduced to 4,864 Gg CO₂eq, confirming that transport optimisation can make a measurable contribution to GHG reduction with limited costs.

In Scenario 2, 10% of the waste is recycled, which reduces landfill emissions to 3,954 Gg CO₂eq and transport emissions to 0,106 Gg CO₂eq. Avoided emissions amount to -0,319 Gg

CO₂eq, and the total net emissions to 3,776 Gg CO₂eq, representing a reduction of approximately 23,6% compared to the baseline scenario.

Scenario 3 includes 15% recycling and 10% composting of biodegradable waste. Landfill emissions amount to 3,489 Gg CO₂eq, while emissions from collection and transport are further reduced to 0,034 Gg and 0,100 Gg CO₂eq, respectively. The most significant contribution in this scenario comes from recycling, which results in avoided emissions of -0,507 Gg CO₂eq. These avoided emissions arise from the difference between the emissions that would have been generated by the production of new raw materials and products and those generated by the recycling process of materials such as paper, plastic, metal, and glass (Figure 2 and Figure 3). The total net emissions are reduced to 3,116 Gg CO₂eq, which is 1,828 Gg (37%) less compared to Scenario 1.

Scenario 3 demonstrates that an integrated waste management approach, combining decentralised measures such as household composting with institutionally organised recycling can lead to significant GHG emission reductions. This model does not require major infrastructure investments but relies on active citizen participation and efficient logistics for the collection and processing of secondary raw materials. Thus, Scenario 3 confirms its potential to become an applicable and adaptable model for other local communities aiming to reduce emissions and align with national and international climate goals. Notably, this approach contributes to building long-term climate resilience and strengthening the capacity of communities to address the challenges of climate change in a systematic and sustainable way.

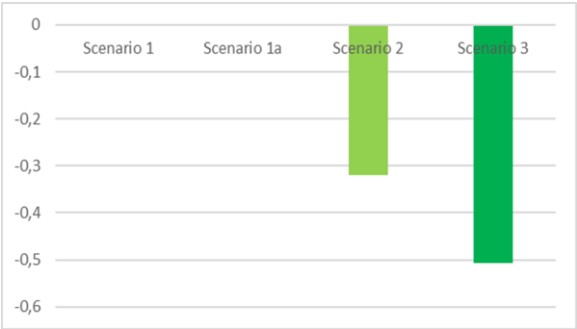


Figure 2. Avoided emissions in scenarios 2 and 3.

Scenario 3 therefore emerges as the recommended strategy in planning local waste management policies aimed at achieving environmental and climate balance.

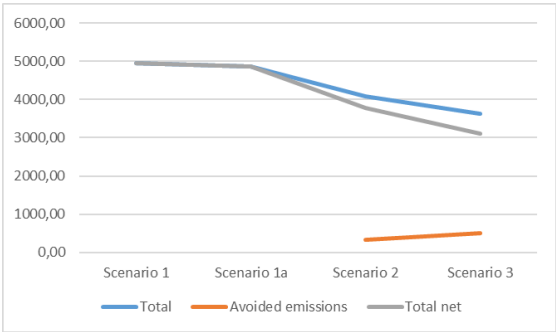


Figure 3. Contribution of avoided emissions to the reduction of total emissions.

The analysis results indicate a gradual reduction in net GHG emissions across the scenarios compared to the reference Scenario 1 (Figure 4). Technical optimisation of transport in Scenario 1a leads to a 1,62% reduction in emissions, while partial recycling in Scenario 2 results in a 23,65% reduction. The greatest reduction, 37%, is achieved in Scenario 3, which combines recycling and

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composting. The findings confirm that integrated approaches with local waste treatment have the highest potential for emissions reduction in the municipal waste sector.

Figure 5 shows the landfill emissions by scenario. The highest emissions are recorded in Scenarios 1 and 1a, where all waste is disposed of without treatment. In Scenario 2, recycling 10% of waste reduces emissions, while Scenario 3, with additional composting, records the lowest emissions. The results confirm that waste valorisation directly reduces GHG emissions.

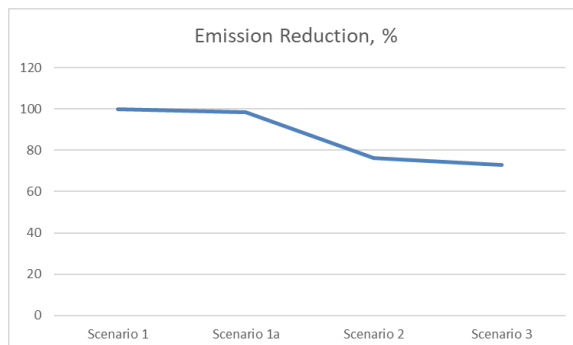


Figure 4. Emission reduction by scenarios compared to Scenario 1.

The obtained values are consistent with previous studies showing that shifting from landfilling to recycling and composting can reduce GHG emissions by 30% to 50% (Lou & Nair, 2009). The analysis by Zero Waste Europe (2019) further confirms that proper bio-waste management can reduce emissions by over 150 kg CO₂eq per capita annually.

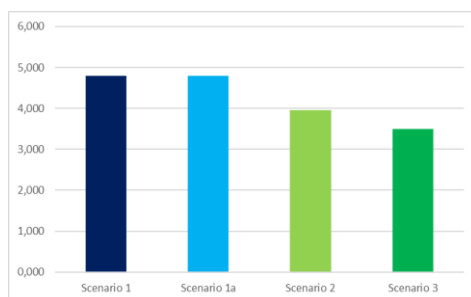


Figure 5. Graphical presentation of GHG emissions from waste disposal according to scenarios.

Special emphasis was placed on household composting, using a conservative avoided emissions factor of 0,054 tCO₂eq per tonne of waste (Vogt et al., 2023). The results show that household composting, especially when combined with other measures, can significantly contribute to emission reduction. The third scenario aligns with circular economy goals and supports Bosnia and Herzegovina's climate commitments under the Paris Agreement and the NDC.

To verify the reliability of emission estimates, a sensitivity analysis was conducted on two key parameters of the IPCC methodology: degradable organic carbon (DOC) and the methane correction factor (MCF). Increasing the DOC from 0,25 to 0,30 results in a methane emission increase of over 10%, while decreasing the MCF from 0,8 to 0,6 indicating improved landfill management, reduces emissions by up to 15%. These results confirm the findings of Zhao et al. (2019) and Rasouli et al. (2025), who reported that variations in these parameters can lead to emission differences of up to 30%. This highlights the need to use locally specific data to improve the accuracy of estimates.

The results obtained in this study can be compared with the analysis by Bjelić et al. (2023), who determined GHG emissions of 560 kg CO₂eq per tonne of waste for the city of Zvornik under

Bijelić, D. et al. (2025). Reducing GHG emissions through improved waste management; case study of the city of Prnjavor. *STED Conference 14(2)*, 29-37.

a scenario similar to the one applied in this study. In contrast, Scenario 3 for the city of Prnjavor, which includes recycling and household composting, showed emissions of 482 kg CO₂eq per tonne of waste. This finding confirms that even partial implementation of recycling and composting measures can lead to significant reductions in GHG emissions with relatively low infrastructure investments. The results may serve as a valuable input for the development of local waste management plans tailored to the specific needs of local communities.

CONCLUSIONS

Based on the conducted research, which included an analysis of GHG emissions from the municipal waste management sector in the city of Prnjavor using the IPCC Tier 1 methodology and a comparison of four different scenarios, the following conclusions can be drawn:

The choice of waste management model has a decisive impact on GHG emissions, landfilling (Scenario 1) results in the highest emissions, while integrated models (Scenario 3) significantly reduce them,

Technical measures such as transport optimization (Scenario 1a) and partial recycling (Scenario 2) enable moderate emission reductions, while combining recycling with composting (Scenario 3) achieves a 37% reduction.

Home composting proves to be a low-cost and effective measure, and integrated approaches allow for the avoidance of emissions associated with raw material production.

Achieving a sustainable waste management system also requires institutional support, education, and active community engagement..

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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ECONOMY AND MANAGEMENT
EKONOMIJA I MENADŽMENT

THE USE OF ARTIFICIAL INTELLIGENCE IN THE RECRUITMENT PROCESS

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ABSTRACT

Redesigning artificial intelligence algorithms to support an efficient, balanced, and objective hiring process is becoming a critical step in achieving and maintaining a competitive advantage in the labor market. This paper aims to highlight the importance of stored data and information generated by individuals, whose neutrality and objectivity cannot always be determined, and which, as such, influence AI algorithms. In this context, the potential ethical and discriminatory implications of using AI in attracting and selecting qualified candidates are examined. The paper underscores the relevance of implementing artificial intelligence in human resource management by promoting fairness, inclusivity, and employee well-being while minimizing potential legal and ethical risks. Its contribution lies in advocating for AI adoption across all stages of the hiring process, while also encouraging both employers and job seekers to maximize AI's potential to achieve their respective goals. To reinforce ethical standards and principles, the paper addresses the issue of assigning responsibility and certifying practitioners, thereby fostering long-term sustainability and broader societal well-being. Theoretical and practical significance is reflected in the paper's conceptualization as a stable foundation for future scientific and research advancements on the impact and application of artificial intelligence in employment processes.

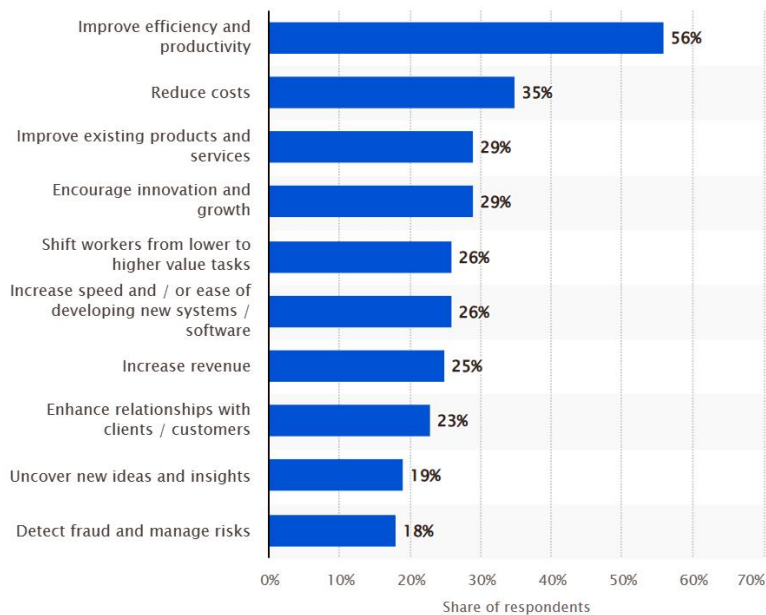
Keywords: Human Resources, Recruitment Process, Artificial Intelligence, Ethics.

INTRODUCTION

The business landscape and labor market are confronting numerous unprecedented challenges, driven by the rapid development of information and communication technologies, the disappearance of once-traditional professions, and the emergence of new ones. Among the various business, legal, and ethical challenges, the use of artificial intelligence stands out as a leading concern. As it becomes increasingly difficult to find candidates whose competencies align with the requirements of vacant positions, AI plays a crucial role in the recruitment process. In this context, the speed at which potential candidates are identified and attracted has become a key factor in maintaining an organization's competitive advantage. This is precisely why the use of artificial intelligence in recruitment is becoming more frequent and comprehensive. By automating numerous activities within the hiring process, AI enables more efficient decision-making, ensuring that the most suitable candidates are given the opportunity to build their careers.

Using new technology, particularly electronic human resource management (E-HRM) as a key tool, organizations can automate numerous manual tasks, enhance data accuracy, and increase overall efficiency. This automation allows HR professionals to shift their focus toward strategic initiatives and talent development. (Gabriel et al., 2024) Artificial intelligence is an increasingly influential technology with applications in modeling complex economic systems, forecasting economic indicators, conducting predictive analytics, supporting decision-making, managing trade and supply chains, and overseeing investments. Additionally, AI fosters innovation and contributes to improving product quality, further enhancing its impact on the economy. (Baltezarević, 2023)

Globally, nearly 60% of organizations anticipate that implementing generative AI will enhance efficiency and productivity. The most frequently cited benefits include cost reduction (35%), improvement of existing products and services (29%), and driving innovation and growth (29%). (Statista, 2024)



Graph 1. Key benefits global organizations hope to achieve with the adoption of generative artificial intelligence (AI) as of 2024 (Statista, 2024).

LITERATURE REVIEW

The process of attracting, identifying, selecting, and integrating candidates is both costly and time-consuming, with poor hiring decisions potentially leading to significant repercussions. To mitigate these challenges, companies are increasingly leveraging the Internet and software technologies to manage applications and evaluate candidates. The integration of artificial intelligence (AI) in recruitment helps minimize decision-making errors and makes the process more cost-effective.

Karaboga and Vardarlier (2020) examined AI usage in recruitment within Turkish companies. Their findings indicate that while AI has value in recruitment, it primarily serves as a supplementary tool rather than a central one. Companies tend to use AI either minimally or not at all, mainly due to concerns that AI may lead to inaccurate candidate assessments.

A study by Marina Budić (2023) conducted in Serbia explored various aspects of AI adoption, revealing public concerns over job losses, the disappearance of certain professions, and potential discrimination by AI systems. The author emphasizes the need for public education on these challenges and strategies to address them. However, other research suggests that HR managers should not view AI recruitment tools as a threat to their roles. Instead, successful recruitment requires collaboration between human resources and AI, with ongoing oversight of AI technologies. (Tsiskaridže et al., 2023)

The existing literature tends to emphasize the negative implications of AI in the hiring process, often portraying robots as process innovations while overlooking the positive effects AI can have on employment. Niame, Damioli et al. (2023) highlight several empirical studies demonstrating that product innovations drive job creation by generating new employment

opportunities in areas such as data processing, transactional procedures, customization, and remote collaboration.

A survey of 297 Chinese companies found that perceived complexity regarding AI adoption acts as a barrier, while technological competence and regulatory support facilitate its implementation. However, factors such as AI's relative advantages, company size, and industry type were not found to have a significant impact on AI adoption. (Pan et al., 2021)

Ligeiro et al. (2024) explored the relationship between organizational attractiveness, intrinsic motivation, perceived novelty, trust in the process, and the intention to adopt, engage in, and complete an AI-assisted recruitment and selection process. Their study, based on a sample of 299 participants from Portugal, revealed that organizational attractiveness and perceived novelty were positively and significantly associated with applying for, engaging in, and completing an AI-assisted recruitment process among participants aged 45 to 54. For those aged 35 to 44, trust in the process played a significant role in their intention to apply and complete an AI-assisted recruitment and selection process.

Sančanin and Penjišević (2024) highlight that under the strong influence of geopolitical challenges, economic turbulence, and negative demographic trends, the labor market is evolving rapidly, reshaping the demand for future professions. Additionally, the authors caution that legal and ethical frameworks struggle to keep pace with the speed and variability of macrorends driven by technological advancements, leading to the emergence of new professions and the decline of existing ones.

Building on the Technology Acceptance Model (TAM), Almeida et al. (2025) developed a framework explaining the intention to adopt AI tools. Their findings suggest that perceived ease of use and perceived usefulness shape attitudes toward AI, which in turn influence the willingness to integrate AI tools into recruitment and selection processes. A qualitative study, based on 100 interviews with recruiters who regularly use AI tools, underscored AI's transformative role in recruitment, emphasizing its potential to enhance efficiency and optimize resource management. Meanwhile, a quantitative study using an online questionnaire completed by 355 recruiters revealed concerns about the potential loss of personal interaction and the need for role adaptation within recruitment. The findings suggest that AI is most effective as a complementary tool rather than a replacement for human decision-making.

KEY AI TECHNOLOGIES IN EMPLOYMENT

In a dynamic and ever-evolving labor market, there is often a shortage of qualified unemployed professionals. As a result, employers must accelerate, simplify, and reduce the costs of identifying and selecting candidates whose competencies align with job requirements. In this context, the key reasons for integrating artificial intelligence (AI) into the recruitment process are emphasized (Oorwin, 2024):

AI in candidate sourcing: AI tools analyze vast amounts of data to identify potential candidates more efficiently than traditional methods.

Resume analysis and screening: AI streamlines the identification of candidates with the right education, skills, and experience, reducing manual review time and allowing recruiters to focus on hiring top talent.

Chatbots for candidate engagement: AI-powered chatbots handle routine inquiries through personalized interactions, freeing managers to focus on strategic goals and enhancing recruitment efficiency.

AI in interview scheduling: Intelligent systems analyze calendars, suggest optimal meeting times, and manage scheduling changes, accelerating the process and improving the candidate experience.

Predictive analytics in hiring: AI evaluates patterns from past hiring cycles to forecast hiring outcomes, enabling more data-driven decision-making.

Video interview analysis: AI assesses candidates' verbal and nonverbal communication, including facial expressions, body language, and speech patterns, providing deeper insights into their abilities.

By incorporating AI into these recruitment processes, companies can improve efficiency, enhance candidate experiences, and optimize talent acquisition strategies.

While it may be too ambitious to quantify all the benefits of artificial intelligence in the hiring process from today's perspective, a report on the future of work, based on insights from 800 global leaders, highlights key expectations (Rayner, 2023):

AI will drive job creation: AI is expected to generate a net increase in jobs over the next five years, with nearly a quarter of existing jobs being replaced by new roles. The automotive industry is projected to experience the highest employment growth, while only four of the 27 industries studied anticipate net job losses, with oil and gas workers being the most vulnerable.

Companies will prioritize AI skills: Among the 25 most critical soft and hard skills in the workplace, AI and big data rank as the top priorities, particularly for companies with more than 50,000 employees. Future public-private collaboration in AI skills training is also expected to play a key role in boosting productivity.

Tasks will be augmented, not fully automated, by AI: Currently, 34% of tasks are automated, and expectations for future automation have been adjusted, with an additional 9% of operational tasks predicted to be automated over the next five years. Research suggests that most management skills are more likely to be enhanced rather than fully automated by AI.

Beyond its potential to improve the recruitment process, AI-driven technology also raises important considerations for organizations evaluating and implementing AI-based hiring solutions. Comparing candidate interview experiences across four key factors—performance anxiety, environmental fit, confidence, and comfort level—Selim Balcioglu and Artar (2024) found that AI-assisted interviews provide a more positive experience for candidates.

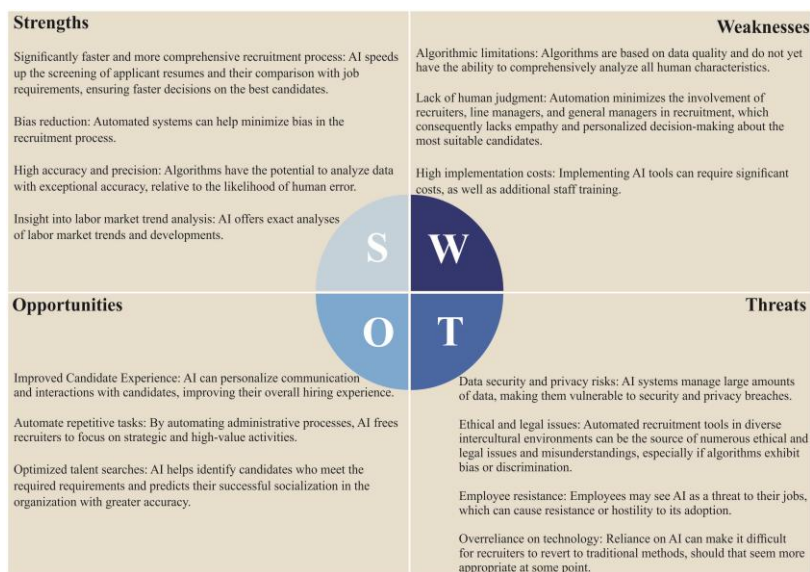


Figure 1. SWOT analysis: employment with the application of artificial intelligence.

In general, the benefits of applying artificial intelligence in the hiring process can be categorized into four key dimensions:

- Quantitative and qualitative improvement of hiring – AI enhances both the efficiency and accuracy of candidate selection.
- Improved integration of advanced analytics – AI enables deeper data-driven insights, optimizing hiring strategies.
- Enhancing hiring through automation – AI streamlines recruitment by automating repetitive tasks, reducing time and costs.

- Driving unbiased decision-making in hiring – AI helps minimize human bias, promoting fairer and more objective candidate evaluations.



Figure 2. Benefits of Using Artificial Intelligence (AI) in Recruitment.

ETHICAL ISSUES OF AI IN RECRUITMENT

High-risk AI systems have the potential to directly or indirectly violate ethical principles, though this is not always the case. However, their development, application, and use raise concerns about ensuring AI remains reliable and responsible. A reliable and responsible AI system is one that is technically stable and safe—one that *“does not allow the processes in which the AI system participates to endanger or marginalize humans, nor does it violate freedom of action, thought, and decision-making to the extent that the rights and achievements preserving these values are rendered meaningless, diminished, or forgotten”* (Official Gazette of the Republic of Serbia, 23/2023).

Christoforaki and Beyan (2022) define AI ethics as a multidisciplinary field encompassing philosophical, legal, social, and technological aspects, aiming to examine their interactions. By considering these dimensions together, the authors argue that a deeper understanding emerges, enabling more effective responses to the challenges posed by the widespread adoption of artificial intelligence, particularly in sensitive fields such as healthcare.

Many of the biases inherent in humans can be transferred to AI, posing a persistent challenge as AI continues to rely on the data it processes and utilizes. This raises an important question from the outset: Who bears responsibility—the data owner, the user, or the developer? Equally critical is determining how to establish ethical standards at national, regional, and global levels in a way that ensures universal acceptance and applicability.

While understanding and embracing AI ethics require long-term, sustained efforts, initial steps have already been taken to provide guidance. In late 2018, the Monetary Authority of Singapore (MAS), in collaboration with Microsoft and Amazon Web Services, introduced the FEAT principles for AI governance: Fairness, Ethics, Accountability, and Transparency. Effective governance, along with robust legislation and regulatory frameworks, is essential for enforcing these ethical principles and ensuring compliance. (Siau & Wang, 2020)

Figure 3 presents a framework for AI ethics, outlining key factors that must be considered when defining ethical guidelines for artificial intelligence.

There is a common belief that applying artificial intelligence in the recruitment process leads to greater objectivity, neutrality, and fairness. However, the evidence does not fully support this claim. In practice, HR professionals involved in recruitment and selection have little control over the attributes that form the data sources AI relies on. As a result, these datasets may contain biases, making AI-driven hiring decisions vulnerable to unintended consequences.

As the BBC (2023) notes, *“if artificial intelligence learns from a dataset that is biased—whether in terms of race, gender, or other factors—it has the potential to reinforce and propagate inaccurate, offensive stereotypes.”* Recognizing these risks, Mujtaba and Mahapatra (2019) explored bias mitigation, fairness, and the promotion of ethical AI algorithms in hiring. Their research highlights the growing use of AI in HR applications such as candidate screening, resume

parsing, and employee turnover prediction. While AI can improve efficiency and reduce some biases through automation, it ultimately depends on human-generated data, meaning human biases can still be embedded in its decision-making processes.

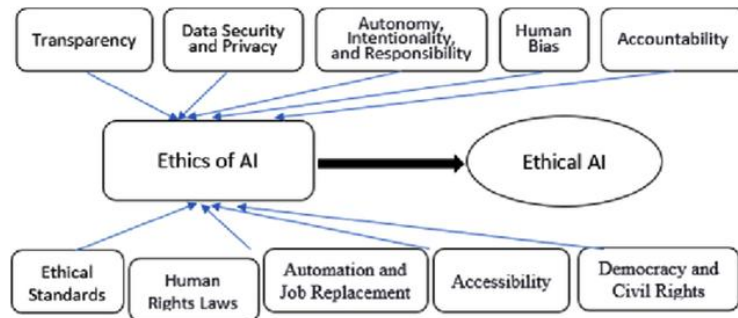


Figure 3. AI Ethics: Framework of building ethical AI (Siau & Wang, 2020).

Drage and Mackersth (2022) examined two key claims made by AI recruitment companies regarding the development and implementation of AI-powered HR tools: (1) AI recruitment can objectively assess candidates by removing gender and race from its systems, and (2) this removal will lead to fairer hiring. The authors argue that these claims are flawed for four reasons:

- The notion of removing gender and race from AI systems reflects a misunderstanding, treating them as isolated attributes rather than deeply embedded systems of power.
- Shifting "diversity work" to other AI recruitment tools risks reinforcing a culture of inequality and discrimination within organizations.
- The supposedly neutral assessment of candidates by AI tools overlooks the inherent power dynamics between the observer and the observed. Specifically, racial history influences how traits are analyzed and aligned with current labor market demands.
- AI recruitment tools do not merely identify the "ideal candidate"; they actively shape this ideal by constructing associations between language, behavior, and identity.

While AI offers many benefits in recruitment, ethical concerns arise when integrating it into organizations. A study by Gupta and Mishra (2022) highlights significant ethical issues, particularly bias. Since AI algorithms rely on input data, they can reflect the subconscious biases of their programmers. Additionally, AI has revived concerns about privacy and data protection.

The future of AI depends on its responsible and ethical use, requiring continuous trust-building and proactive risk management. Standardizing and ensuring transparency in AI-generated data can foster public trust and confidence. Otherwise, AI's immense potential to improve quality of life could be misused, turning it into a harmful tool instead of a beneficial one (Sančanin & Penjišević, 2022).

CONCLUSIONS

Although artificial intelligence cannot be considered entirely impartial in the recruitment process—since existing data and information reflect the subjectivity of their creators—it offers numerous innovative solutions.

First and foremost, AI algorithms identify candidates with the required competencies more quickly and accurately, allowing human resources managers to dedicate more time to applicants with the right knowledge, abilities, and skills. Additionally, AI-assisted recruitment has streamlined and accelerated the application process for job seekers. However, it has also made it easier for unqualified candidates to apply, significantly more than in conventional hiring methods. Fortunately, AI algorithms filter out such candidates at the preliminary stage by verifying whether they meet the formal requirements.

With the automation of the entire recruitment process, recruiters are relieved of administrative burdens, while candidates benefit from a significantly improved experience. This, in turn, positively impacts the employer's reputation, reinforcing their image as a desirable workplace.

Since most studies examine the role of artificial intelligence in recruitment from the perspective of employers, a shift in focus is needed to place job seekers at the center of attention. Moreover, accountability in AI-driven recruitment must be individualized to prevent unethical practices.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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ELECTRONIC MANAGEMENT OF THE PUBLIC ADMINISTRATION, A PROCESS THAT INFLUENCES ITS EFFECTIVENESS AND RESPONSIBILITY

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ABSTRACT

Electronic governance of the administration affects the increase of the effectiveness, efficiency, responsibility and motivation of the administration. Hence, the subject of the research is to consider all issues related to the electronic governance system, as well as to analyze the state of the field of electronic governance in the Republic of North Macedonia. The methodology of the work is based on the use of a quantitative method, interviews with administrative officials in 30 state bodies at the central and local levels. In addition, a content analysis of all legal, regulatory acts, research results and other documents relevant to the research was made. The questionnaire contains three groups of questions: the first group of questions refers to the regulatory framework and its applicability, the second group of questions refers to the financial, technical and personnel capacities necessary for the implementation of the electronic governance system, the third category of questions refers to the implementation and acceptance of the electronic governance system by all relevant factors. The results indicate partiality in the establishment of electronic governance systems, lack of financial resources and professional capacities for the establishment and applicability of such systems, as well as resistance to changes at all levels of governance. The final conclusion is the necessity to establish a unified public sector management software in all state bodies that will cover all segments of efficient administration management at the central and local levels.

Keywords: efficiency, electronic governance, state and local bodies, administration.

INTRODUCTION

The new era has imposed a need for changes in the approach to managing public administration. Hence, the approach to managing public administration is in continuous growth and development, which is reflected in new trends in managing it. One of the new approaches to managing public administration is the New Public Management, which favors independence in the process of realizing the functions of public administration on the one hand, and at the expense of this, the responsibility of the administration is strengthened on the other hand. (Gruening 2001).

The new public management is aimed at decentralizing the process of managing public administration, which means transferring administrative responsibilities from the central to the local government. This model imposes the transfer of public powers of the state to private entities that provide public services with their own investments. In return, the state strengthens control mechanisms by introducing new ways and approaches to controlling and managing public activities. In order to implement the new management model, it is necessary that it be supported by the establishment of an electronic management system. The Republic of North Macedonia (RNM) has decided to implement an Electronic Management System in all previous strategies that have been continuously adopted by the Governments of the Republic of North Macedonia in the last 10 years. Hence, this paper focuses on electronic management of public administration in order to understand all the factors necessary for its efficient implementation. The basic condition for starting the implementation of this management system is the support of appropriate normative

acts, then financial capacities for the implementation and maintenance of technical means as an indispensable condition for efficient implementation and of course the most important condition is the human resources capacities, appropriately trained personnel who will maintain and manage these technical means. These basic factors impose certain rules of conduct between employees within state and local authorities, as well as between all state and local authorities in the country, and ultimately a way of dealing with citizens to effectively meet their needs. When analyzing e-governance, we need to distinguish between electronic communication and electronic management, which does not mean that both internal and external electronic communication is an important segment for efficient management. An electronic management system is reflected in fast and transparent internal communication, between supervisors and employees, clear assignment of work tasks from supervisors to employees, which allows for control over the completion of work tasks by the administration. Furthermore, this system influences clear communication between employees, when exchanging information in the process of performing work tasks, whether they receive the information in a timely manner, which imposes easy determination of responsibility towards those who are late or are unprofessional in their domain of work. Hence, we point to the conclusion that electronic administration management affects the increase in effectiveness, efficiency, accountability and influences the motivation of employees in the administration, if those who are efficient in their work are appropriately rewarded. In order to implement an e-governance system for state bodies, the following steps are necessary: The e-governance and management system should be based on an appropriate and mandatory normative framework of a state that emerges as a policy from a single strategy of a country and that the state should strive towards its implementation. Then this government policy should be established within the strategies of each individual state body. To ensure the necessary financial resources are provided, they need to be reliable and long-term, and appropriate technical means and personnel must be provided to manage this complex system and ensure its full implementation and sustainability. Appropriate training of the administration and management staff, as an indispensable part of the efficient implementation and functioning of the electronic administration management system, so-called E-Government. The management system should be linked to a program for motivating the administration. The system should be subject to continuous evaluation by citizens, service users, regarding the manner and efficiency of the administration's provision of services.

RESEARCH METHODOLOGY

The aim of the research is to identify all issues that indicate the need and possibility of establishing an electronic governance system, as well as to analyze all factors related to electronic governance in the Republic of North Macedonia. Thus, the purpose of the paper requires examining all relevant indicators related to the process of e-governance in state bodies, normative, technical and personnel capacities. Also, the aim of the paper is to determine the manner in which the administration is managed, whether an electronic system of management and communication has been established in state bodies. Then, if such a system has been established, is it applicable? It is important to examine whether procedures and rules for internal communication between employees have been established, how work tasks are assigned by the superior to the employee, how external communication with service users and partner institutions is achieved, and whether the established electronic systems are functional according to the needs of citizens.

The methodology of the paper is based on the use of a quantitative method of interviews with administrative officials in 30 state bodies at the central and local levels. The questionnaire contains three groups of questions: the first group of questions refers to the regulatory framework and its applicability; the second group of questions refers to the implementation of the electronic management system in state bodies, real capacities, financial, technical, trained staff; the third category of questions refers to the implementation and how changes to the already introduced electronic management system are accepted by the administration, managers and service users - citizens. In addition, the methodology of the paper is based on an analysis of the normative acts relevant to the subject of the research, analyzing previous research and indicators at the European and global level related to the subject of the research.

Normative acts relevant to the research are the Law on Electronic Documents, Electronic Identification and Confidential Services: Law on Electronic Governance and Electronic Services; Law on Electronic Communications ("Official Gazette of the Republic of Macedonia" 13/05, 14/07, 55/07 and 98/08); Law on Data in Electronic Form and Electronic Signature ("Official Gazette of the Republic of Macedonia" No. 34/01, 6/02 and 98/08); Law on Electronic Governance ("Official Gazette of the Republic of Macedonia" No. 105/09); Law on Personal Data Protection ("Official Gazette of the Republic of Macedonia" No. 7/05 and 103/08); Law on Classified Information ("Official Gazette of the Republic of Macedonia" No. 9/04 and 113/07); Law on Free Access to Information ("Official Gazette of the Republic of Macedonia" No. 13/06 and 86/08); Rulebook on technical and organizational measures for ensuring confidentiality and protection of personal data processing ("Official Gazette of the Republic of Macedonia" No. 38/09); Law on Electronic Commerce ("Official Gazette of the Republic of Macedonia" No. 133/2007); Law on Archival Materials ("Official Gazette of the Republic of Macedonia" No. 36/90 and 36/95); Decree on Office and Archival Operations ("Official Gazette of the Republic of Macedonia" No. 58/96).

ANALYSIS OF RESEARCH RESULTS

As we mentioned, the research methodology was based on a qualitative analysis of interviews conducted with over 30 respondents in the state administration and local self-government employed in various job categories. The first group of questions related to the effect of the applicability of normative acts. Thus, 80% of the respondents answered that they have adjusted the laws relating to electronic operations, so that all by-laws arising from the laws have been developed. If we compare this with the research conducted in local self-government units and the monitoring of public administration, the conclusion that there is an effect of the new legal solutions and strategies related to information technology coincides. The applicability of these legal solutions encounters problems and difficulties due to financial, technical and personnel capacities that should serve electronic operations in state bodies. So far, electronic systems have been established in state bodies in the Republic of North Macedonia that relate to electronic communication of state bodies with citizens, as well as electronic communication between state bodies, which enable faster exchange of information and greater transparency of state bodies. Also, electronic archiving in state, public and local government bodies allows for clear records, storage and archiving of archival material. State bodies have computers for employees and sectors that lack staff for software operation and computer maintenance. State bodies are not connected in a single E-Government system, which causes difficulties in the communication process. All municipalities have servers, but in a small number of municipalities the computers are connected to a domain, in some there is partial implementation, and in some there is none at all. Awareness among local government units about the use of licensed software has increased. When it comes to communication with citizens and companies and openness, a high percentage of 90 percent of state and local authorities have their own website where they publish information about their work. In terms of electronic administration management, there is no such management system. Work tasks are assigned manually in paper form, there is no monitoring of work nor an electronic hierarchy of responsibilities system through which responsibility can be easily located. The one-stop shop systems that have already been established do not aim to control the work of the administration; they serve exclusively for the electronic delivery of information to citizens, but not to control whether they have responded to the service efficiently and in a timely manner. A one-stop shop system has been established in 50% of state bodies. It is important to emphasize that state and local bodies do not have software for electronic recording of human resources for obtaining the benefits we previously mentioned. It is necessary to establish a unified public sector management software in all state bodies that will cover all segments of efficient management and achievement of results in the administration. Regarding the third group of questions, there is still resistance among the administration to accepting the new way of electronic working, especially among the older category of workers, the same applies to older clients who use services. The findings regarding dissatisfaction and resistance to the new way of working coincide. It is believed that even

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management staff who are supposed to assign tasks electronically avoid this way of working, because it requires transparency in both their work and the evaluation of the administration. Until electronic software is introduced for monitoring the work of the administration, i.e. electronic management of work tasks, we cannot talk about an efficient administration that will be motivated and responsible and will respond to the needs of citizens in a fast and efficient manner. When analyzing e-governance, we need to distinguish between electronic communication and electronic management, which does not mean that electronic communication, both internal and external, is not an important segment of effective management. The regulatory framework in the Republic of North Macedonia is focused on electronic communication between state bodies, certain state bodies have developed software for obtaining feedback from citizens for certain services. Electronic archiving of documents is a mandatory tool and is applied in all state and local authorities, and the introduction of standardization of work processes through ISO standards is partially represented since it is not a mandatory legal obligation. From previous research, it can be seen that in the Republic of North Macedonia, e-government projects are being partially implemented. In terms of cooperation between state bodies in the Republic of North Macedonia, a one-stop shop system has been established in the domains of real estate cadastre, healthcare system, public procurement, treasury system, ecology, judiciary, documents of the personal status of citizens (birth certificate, citizenship, death certificate, etc.), judiciary, company registration, etc. Although the Law on General Administrative Procedure (Article 57, Official Gazette of the Republic of Macedonia, No. 124 of 23.07.2015). requires the official conducting the procedure to independently obtain the evidence, data and facts for which official records are kept in his public body or in another public body, ex officio and electronically, practice shows minimal applicability of this provision. With the amendments to the Law on Electronic Governance adopted in 2016, and in order to implement the provisions of the Law on Electronic Governance, a service for electronic registered delivery of documents with and between institutions was introduced, which should ensure fast, reliable and secure delivery of documents. The delivery enables efficiency of the procedure and its cost-effectiveness, while fully respecting the highest security standards. So far, two commercial systems have been certified to provide this service. (Public Administration Reform Strategy 2018-2022).

The Ministry of Finance has established software for citizen services related to privatization, so that citizens can track the progress of cases and act in accordance with the requests of officials. The current electronic systems established in state and local authorities in the Republic of North Macedonia are aimed only at providing information between state authorities and citizens, but do not represent e-governance in the administration. The electronic administration management system involves monitoring the way the administration works, electronically assigning work tasks until their implementation, the deadline for performing the work, the quality of the work completion and measuring the work, as a basis for measuring the efficiency of employees, which can be further upgraded with measures for motivation, reward or responsibility, punishment. The perception of Macedonian civil society organizations is quite negative when it comes to service delivery. Many civil society organizations believe that one-stop shops and administrative service providers are not easily accessible to all citizens due to their geographical distribution. Service providers also have all necessary forms available online and inform citizens about their rights and obligations. On the other hand, the concerns of citizens and civil society organizations are confirmed by the situation of the sample of service providers analyzed, as e-services are rare and websites do not offer guidelines for citizen participation. (Related publications of ZG - Center for Change Management: "Evaluation of Policies for Improving Public Services" (2020)

From the latest analyses of citizen satisfaction with public administration conducted in recent years, the general perception of citizens in Macedonia regarding the quality and accessibility of administrative services is divided. Almost the same percentage of citizens believe and disagree that dealing with the administration has become easier in the past two years. This leads us to the conclusion that their experiences in obtaining services depend on the institution providing the service and the type of services provided. However, research has also shown that digitalization has contributed to the positive opinion of citizens, as well as the general tendency and commitment of

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service providers to provide broader e-services. However, although citizens consider e-services to be a step forward and believe they are easy to use, they rarely use them. On the other hand, it is evident that the Government needs to improve communication and consultations with citizens, as the perception is completely negative. Half of citizens believe that the administration has not asked for their opinion on how to improve administrative services. (UNDP Public Opinion Survey Reports on Citizen Satisfaction with Local Self-Government in the Republic of North Macedonia 2021, 2022, 2023, 2024).

CONCLUSION AND RECOMMENDATIONS FROM THE RESEARCH

Given the above analysis, we can conclude that the Republic of North Macedonia has adopted a large number of laws and bylaws related to electronic business, but there are legal gaps that prevent their implementation. The current acts only refer to electronic communication, between state and local authorities and with citizens for the exchange of information and the issuance of certain electronic personal documents, only in certain areas. It is necessary to establish a single unified management and communication system for all state and local authorities, to be supported by the Laws as a mandatory obligation. To determine the ways in which financial resources, technical means and trained personnel will be provided to manage this complex system and ensure its full implementation and sustainability. Appropriate training of the administration and management staff is an indispensable part of the efficient implementation and functioning of the electronic administration management system, called E-Government. The management system should be necessarily linked to a program for motivating the administration. The system should be subject to continuous evaluation by citizens, service users, on the manner and efficiency of service provision by the administration. State bodies should be electronically connected so that they can quickly respond to citizens' questions, problems and needs, when collecting information, giving opinions, providing documents, etc. The administration should have a clear goal for its role in the state body and in the system in general, which means being focused on personal development of knowledge and skills, as well as having a clear position for citizens in the system. As a significant segment in the process of efficient e-governance, the necessity of establishing the Human Resources Management Information System (HRMIS) aims to improve the efficiency of human resources management, and thus the quality of the work of public sector institutions.

Already established information systems should be supplemented, upgraded and replaced with new technologies, and this should be supported by continuous control and supervision by appropriate oversight institutions. The overall e-governance system should be based on sustainable electronic communication networks and systems. It is necessary to conduct campaigns about the advantages and benefits of building and developing electronic communication networks and electronic governance systems as the basis for the information society. Institutions need to proactively and systematically increase the level of awareness and information on e-services to encourage the use of e-services. All institutions should have functional public feedback channels on their websites, giving citizens a network in which to evaluate service delivery. The one-stop shop system should be easily accessible to all citizens and appropriately distributed throughout the country, so that all citizens can have easy access.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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MODELS FOR ESTIMATING PRODUCTION PHASE DURATION AS A FOUNDATION FOR EFFICIENT PRODUCTION MANAGEMENT

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ABSTRACT

In modern manufacturing systems, accurately defining and managing the duration of individual production phases is crucial for achieving high efficiency and reliable delivery timelines. This paper presents two methodologically grounded models for estimating the duration of the production phase: one based on the technological (ideal) cycle, and the other on the projected (realistic) cycle that incorporates organizational and logistical constraints. A case study is provided involving the packaging of a 20 mm round into a crate, part of the production program of the 'Sloboda' Co. - Cacak, Serbia.

By analyzing the flow coefficient, defined as the ratio between the actual and ideal/projected cycle durations, potential inefficiencies within the production process can be identified. The results suggest that predefining projected durations for each production phase significantly improves planning accuracy and coordination across the production flow. The proposed models serve as a practical decision-support tool within production management systems.

Keywords: production management, production phase, production cycle, flow coefficient.

INTRODUCTION AND PREVIOUS RESEARCH

In today's dynamic manufacturing environments, the ability to accurately plan, schedule, and control production processes is a critical determinant of operational efficiency and market competitiveness. The duration of each production phase plays a central role in determining delivery accuracy, resource utilization, and the overall responsiveness of the production system.

Theoretical and practical studies have increasingly focused on the application of diverse methods and techniques to reduce the duration of the production cycle. The complexity of production processes and the need for efficiency improvements have led to the development of various models, performance measures, and analytical approaches.

Aouam and Uzsoy (Aouam & Uzsoy, 2014) proposed zero-order production planning models that incorporate stochastic demand and workload-dependent lead times, providing a valuable framework for understanding uncertainties in production environments. Similarly, Huang and Yao (Huang & Yao, 2013) investigated optimal lot-sizing and scheduling in serial-type supply chains using time-varying policies, highlighting the role of planning dynamics in cycle time management.

Jovanović, Milanović, and Djukić (Jovanović et al., 2014) introduced two flow coefficients, the ratio of actual to planned cycle time and the ratio of actual to technological (ideal) cycle time—as indicators of production efficiency. Their work emphasized the importance of quantifying these relationships to identify inefficiencies and guide scheduling improvements.

Macchi (Macchi, 2008) examined performance trade-offs between flow time and throughput in complex manufacturing systems. His research provided context for evaluating flow coefficients within broader production performance strategies.

Material Flow Cost Accounting (MFCA) has also emerged as a significant tool for identifying and analyzing inefficiencies in production systems. Dierkes and Siepelmeyer (Dierkes & Siepelmeyer, 2025) developed an MFCA model that incorporates multiple inefficiency factors such as waste, rework, and recycling, enabling detailed cost assessments related to material losses.

Jovanović, J., & Perišić, D. (2025). Models for estimating production phase duration as a foundation for efficient production management. *STED Conference 14*(2), 55-60.

Takakuwa, Zhao, and Ichimura (Takakuwa et al., 2014) applied simulation techniques within the MFCA framework to analyze material flows and improve both environmental and economic performance.

Research has also explored more specialized aspects of cycle time estimation and material flow. Chincholkar and Herrmann (Chincholkar & Herrmann, 2008) modeled manufacturing cycle time and throughput in flow shops affected by process drift and inspections, using queuing network approximations. Dong et al. (Dong et al., 2016) investigated material flow in aluminum extrusion, emphasizing die modifications to improve flow uniformity in complex profiles.

Efficient material handling is another key concern. Ellis et al. (Ellis et al., 2010) proposed a multi-commodity network flow model for optimizing assembly facility operations, stressing the role of layout and flow path design in reducing handling costs. In a similar vein, Gould and Colwill (Gould & Colwill, 2015) developed a framework for assessing material flow in manufacturing systems, aiming to detect inefficiencies and propose targeted improvements.

Stanisavljev, Zakin, and Istrat (Stanisavljev et al., 2014) argued that production cycle time in real-world scenarios is stochastic rather than deterministic. Their study, based on data from Serbian manufacturing enterprises, supports the use of a multi-dimensional model of production scheduling and monitoring rooted in modern organizational theory. This model emphasizes interconnectivity between production elements and the benefits of integrated planning.

On a more systemic level, Müller et al. (Müller et al., 2014) reviewed dynamic material flow analysis (MFA) methods used to model metal stocks and flows. Their work categorizes modeling approaches according to the ODD protocol (Overview, Design concepts, Details), accounting for dispersion, spatial flow dimensions, and uncertainty management. This review serves as a foundation for understanding long-term material usage trends and sustainability implications.

Sendra, Gabarrell, and Vicent (Sendra et al., 2007) adapted MFA methodology to industrial areas, particularly in Catalonia, Spain. Their research integrated material, water, and energy flows to assess resource efficiency and identify opportunities for waste reduction. By demonstrating the effectiveness of MFA indicators even with limited data, the study underscored the value of localized and tailored approaches to improving industrial sustainability.

Together, these studies form a comprehensive body of knowledge that spans from theoretical modeling of production cycles and flow dynamics to applied frameworks like MFCA and MFA. This literature highlights the importance of accurate cycle time estimation, efficiency measurement through flow coefficients, and the continuous monitoring and improvement of material flows across diverse industrial contexts.

In Table 1, the reviewed studies are organized into thematic groups, with a concise summary of the research focus for each study.

This paper addresses the need for precise estimation models of production phase duration by introducing two complementary approaches: one that reflects the ideal technological cycle, and another that incorporates realistic conditions through a projected cycle model.

The aim is to demonstrate how these models can serve as analytical tools to support effective production planning and management, with particular emphasis on identifying and minimizing inefficiencies.

A real-world case study is presented from the production program of the defense industry company *Sloboda Cacak*, focusing on the packaging phase of a 20mm caliber round. Through this example, the paper illustrates how the proposed models can be applied to complex manufacturing systems and how the analysis of the flow coefficient—defined as the ratio between actual and ideal/projected cycle times—can guide decision-making in production management.

The structure of the paper comprises the following chapters:

- Models for calculating cycle duration and flow coefficient,
- Application of the proposed model: case study and results,
- Conclusion and future research, and
- Literature.

Table 1. Grouping of relevant studies by research focus.

Group	Authors and Year	Focus / Contribution
1. Production Cycle Time Modeling and Scheduling Optimization	Jovanović et al. (2014)	Introduced K_p and K_t coefficients for measuring and improving production efficiency.
	Chincholkar & Herrmann (2008)	Developed a model for estimating cycle time and throughput in flow shops with inspections.
	Stanisavljev et al. (2014)	Proposed a multidimensional model for stochastic production cycle scheduling and monitoring.
2. Flow Coefficients and Performance Trade-offs	Macchi (2008)	Analyzed trade-offs between flow time and throughput in complex systems.
	Jovanović et al. (2014)	Applied flow coefficients to real production systems for scheduling improvement.
3. Material Flow Cost Accounting (MFCA)	Dierkes & Siepelmeyer (2025)	Developed an MFCA model incorporating waste, rework, and recycling inefficiencies.
	Takakuwa et al. (2014)	Used simulation with MFCA to detect losses and improve flow efficiency.
4. Material Flow Analysis (MFA) and Resource Efficiency	Müller et al. (2014)	Reviewed dynamic MFA approaches for modeling metal stocks and material dispersion.
	Sendra et al. (2007)	Applied MFA to industrial areas to assess resource efficiency and identify inefficiencies.
5. Material Flow Optimization and Layout Design	Dong et al. (2016)	Improved material flow in aluminum extrusion via die design modifications.
	Ellis et al. (2010)	Developed a network flow model to optimize assembly facility material handling.
	Gould & Colwill (2015)	Proposed a framework for assessing and improving material flow in manufacturing.
6. Planning Models in Production and Supply Chains	Aouam & Uzsoy (2014)	Introduced zero-order planning models with stochastic demand and variable lead times.
	Huang & Yao (2013)	Studied lot-sizing and scheduling in serial supply chains with time-varying policies.

MODELS FOR CALCULATING CYCLE DURATION AND FLOW COEFFICIENT

From the perspective of theoretical considerations, industrial practice, and duration, three types of cycles can be distinguished: the technological cycle or ideal production cycle ($T_t \equiv T_{ci}$), the production (actual) cycle (T_{cs}), and the projected production cycle (T_{cp}), as shown in Figure 1.

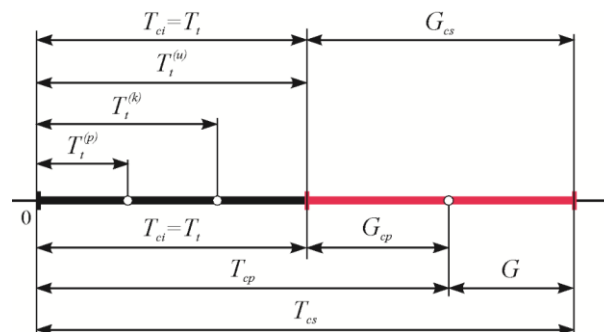


Figure 1. Types of cycles according to duration.

Technological manufacturing cycle T_t , which is also an ideal cycle T_{ci} includes the time needed for performing all n operations predicted by the technological procedure, on the products of a single lot. Production organization plays critical role in determining the technological cycle, where moves may be consecutive (Relation (1)), parallel (Relation (2)) and combined (Relation (3)), depending on the type of production consisting of a complex set of features. The combined type of work flow in manufacturing process is most often encountered in serial production. Its goal is to eliminate downtimes emerging at some workplaces (operations) at parallel type due to different duration of successive operations.

$$T_t^{(u)} = q \cdot \sum_{i=1}^n t_i, \quad (1)$$

$$T_t^{(p)} = \sum_{i=1}^n t_i + (q - 1) \cdot t_{max}, \quad (2)$$

$$T_t^{(k)} = \sum_{i=1}^n t_i + (q - 1) \cdot (\sum_k t_k - \sum_j t_j), \\ (t_{k-1} < t_k \geq t_{k+1}, k = \overline{1, n}) \wedge (t_{j-1} \geq t_j < t_{j+1}, j = \overline{2, n-1}), \quad (3)$$

Where:

t_i - total time per technological operation in norm hour/piece
 q - lot size in pieces

The projected production cycle duration T_{cp} , Relation (4), aside from productive and non-productive cycle times, predicted by technological procedures, takes into account: scheduled manufacturing capacity utilization level, real manufacturing conditions per operation and scheduled losses in a cycle. The first step in the scheduling process is calculating the manufacturing cycle time duration per operation (τ_i) using Relation (5), with respect to real manufacturing conditions: number of workplaces per technological operation (r_m), number of shifts per day (S_n), average norm-hour execution (p_n), and norm-set capacity per shift (q_s). Inventories in unfinished production and losses due to quality inadequacy are included in calculations via the formulas for planning the quantity (q) of the product to be produced. In the second step, it is needed to adopt total losses in the cycle G_{cp} , and then to determine average partial losses between technological operations $\Delta\tau$.

$$T_{cp} = \tau_1 + (n - 1) \cdot \Delta\tau + \sum_p^k (\tau_p - \tau_{p-1}), p: \tau_p > \tau_{p-1}, \quad (4)$$

$$\tau_1 = q / (q_s \cdot S_n \cdot r_m \cdot p_n), \quad (5)$$

The flow coefficient is a measure of the efficiency of the production process. It can be calculated in two ways. The first as the ratio of the actual and technological length of the production cycle, usually according to the sequential way of moving objects of work, Relation (6). And another way as the ratio of the actual and projected length of the production cycle, Relation (7).

$$K_t = T_{cs} / T_t^{(u)}, \quad (6)$$

$$K_p = T_{cs} / T_{cp}, \quad (7)$$

Viewed from the angle of the manufacturing system, flow coefficient K_p has a higher use value, because the accomplished values of the cycle are correlated with scheduled (planned) values. In this context, model design becomes a cyclic process with the aim to minimize total

Table 2. Parameters for technological and projected cycle calculations.

Order of operation	Time per operation t_i [cmh/piece]	Capacity in a shift q_{si} [piece/shift]	t_k	t_j	S_n	r_m	p_n	p
1	75	10000			1	2	1.25	
2	125	6000	+		1	2	1.18	+
3	125	6000			1	2	1.19	
4	50	15000		+	1	2	1.2	
5	63	12000			1	3	1.16	
6	220	3400	+		1	4	1.15	+
7	62	12000			1	3	1.18	
8	14	55000			1	1	1.25	
9	14	55000		+	1	1	1.25	
10	30	25000			1	3	1.24	
11	188	4000	+		1	3	1.18	+
12	62	12000			1	4	1.19	
$q = 10200$ pieces		$\Delta\tau = 0.5$ shift = 3.75 h						

Using formulas (1), (3), (4), (5), (6), and (7), along with the parameters listed in Table 2, the results were obtained and are presented through expressions (8), (9), (10), and (11).

$$T_t^{(u)} = (10200 \cdot 0.01028) / 7.5 = 14 \text{ shift}, \quad (8)$$

$$T_t^{(k)} = (0.01028 + (10200 - 1) \cdot (0.00533 - 0.00064)) / 7.5 = 7 \text{ shift}, \quad (9)$$

$$T_{cp} = 0.41 + (12 - 1) \cdot 0.5 + 1.33 = 7.24 \text{ shift}, \quad (10)$$

$$K_t = T_{cs} / 14, \quad K_p = T_{cs} / 7.24, \quad (11)$$

The length of the cycle according to the first model is 14 shifts (consecutive mode) and 7 shifts (combined mode), and according to the second model 7.24 shifts (combined mode). The projected values are close to the ideal length of the cycle, of course if the combined way of movement of the objects of work is observed, so that both can be used for planning and production management. However, in the second model, that is, the model for designing the production cycle, it is also necessary to take into account the degree of utilization of machine capacities for the corresponding operations. This can be quantitatively incorporated by introducing a machine utilization coefficient, defined as the ratio between the actual machine working time and the available scheduled time for each operation. Integrating this parameter into the model enables a more realistic estimation of the production cycle duration, particularly in environments with variable workload distribution or partial equipment utilization.

CONCLUSION AND FUTURE RESEARCH

This paper presents two models for estimating the duration of the production phase cycle, serving as a foundation for efficient production management. The first model calculates the ideal (technological) cycle, while the second focuses on the projected production cycle, accounting for real-world organizational and logistical constraints. A detailed calculation is provided for the packaging phase of a 20mm round into a crate, which is part of the production program of the 'Sloboda' Co. Cacak. The length of the cycle according to the first model is 14 shifts (consecutive mode) and 7 shifts (combined mode), and according to the second model 7.24 shifts (combined mode). The projected values are close to the ideal length of the cycle, of course if the combined way of movement of the objects of work is observed, so that both can be used for planning and production management. For the calculation of the flow coefficient K_f , it is necessary to take a technological cycle that corresponds to the type of production and not, as has been the practice until now, to always take the sequential way of movement of the objects of work.

Future research should be directed towards the identification of the causes of losses and the analysis of the degree of utilization of production capacities, which should be included in the model for designing the production cycle of each operation. In addition, it is necessary to analyze the actual length of the cycle and determine the values of the flow coefficient, which is an indicator of potential inefficiency in the production process.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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RANKING OF THE SOFTWARE PACKAGES FOR PROJECT MANAGEMENT USING INTEGRATED MCDM METHODS

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ABSTRACT

In this paper, the ranking of selected software packages for project management is performed. The aim is to rank project management software packages based on predefined criteria and to show that MCDM methods can yield varying results even when analyzing the same problem. This shows that MCDM can be a useful tool for simplifying the observed problem, but the final decision should be given by the decision-maker.

When deciding using quantitative MCDM methods, it is necessary to know the criteria weights and input data that will be used for comparing alternatives. In this paper, AHP, CRITIC and CILOS methods for determining criteria weights and VIKOR, TOPSIS, COPRAS, SAW and GRA methods for alternative ranking will be used.

A brief literary review of the chosen methods will be presented, followed by a comparative analysis of the software packages. Finally, tabular and graphic representations of the alternative rankings obtained from the different methods are provided.

Keywords: project management, MCDM method, ranking, alternative, criteria.

INTRODUCTION

Software Project Management is an umbrella term used to refer to the systematic execution of processes such as planning, monitoring, staffing, and leading software projects to minimize the cost of software production while attaining high quality end product (Lee & Chen, 2022). Project managers need to choose a suitable set of tools in the marketplace to improve productivity and avoid violating time and budget constraints (Akbar et al., 2022).

When decision-making, a lot of factors can influence the final decision. Multi-criteria decision-making (MCDM) methods help with eliminating complex and unnecessary information thus making the decision process easier. The MCDM process deals with situations involving the selection, sorting and ranking of the best alternative from several options based on selected criteria with the help of mathematical models (Chakraborty et al., 2024).

The topic of selecting the optimum project management software has been widely researched and can be found in multiple papers, for example: Akbar et al., 2023; Cicibas et al., 2010; Manole & Avramescu, 2017; Milojević et al., 2023; Mitrović et al., 2011; Milin et al., 2012.

When using quantitative MCDM methods it is necessary to know the criteria weights and input data that will be used for evaluating optimal alternative. In this paper, several MCDM methods will be used for determining criteria weight and alternative ranking.

Though they help with decision-making process, MCDM methods can give different results even when criteria weight or input data is not changed. A number of papers deal with comparative analysis of the mentioned methods, such as Podvezko, 2011; Radulescu & Radulescu, 2024; Özcan & Çelik, 2021; Sari, 2018; Opricovic & Tzeng, 2004; Kokoç & Ersöz, 2019; Misra & Ray 2012; Ustinovichius, 2007.

Most approaches to determining weight criteria can be divided into subjective and objective (Žižović et al., 2020). Subjective approaches are based on determining criteria weight using information from decision-makers or experts included in the decision process and reflects the

Perišić, D., & Jovanović, J. (2025). Ranking of the software packages for project management using integrated MCDM methods. *STED Conference 14*(2), 61-69.

subjective opinion and intuition of decision-makers which means that decision-makers influence the decision-making process (Žižović et al., 2020). Subjective techniques require the participation of the decision-maker in the weighting procedure (Paradowski, 2021). Contrary to subjective approaches, objective approaches are based on determining criteria weight using data that is present in the initial decision matrix and disregard the opinion of decision-makers (Žižović et al., 2020). Objective weighting methods determine criterion weights based on mathematical formulas (Paradowski, 2021).

In this paper 3 approaches are used: AHP, CRITIC and CILOS.

The Analytic Hierarchy Process (AHP) is a subjective multi-criteria decision-making approach in which factors are arranged in a hierarchic structure (Saaty, 1990). It is used to derive ratio scales from both discrete and continuous paired comparisons. These comparisons may be taken from actual measurements or from a fundamental scale which reflects the relative strength of preferences and feelings (Saaty, 1987). In AHP criteria weights are assessed subjectively given that the decision-maker can provide scaled preferences of pairs of decision criteria and alternatives with acceptable inconsistency (Aomar, 2010).

Criteria Importance Through Intercriteria Correlation (CRITIC) is an objective approach which considers both contrast intensity and conflict which are contained in the structure of the decision problem (Diakoulaki et al., 1995). This approach uses the standard deviation quantifies the contrast intensity of the corresponding criterion and the linear correlation coefficient (Diakoulaki et al., 1995).

Criterion Impact Loss (CILOS) is an objective method that is used for determining a relative impact loss experienced by the criterion of an alternative, when another criterion is chosen to be the best (Zavadskas & Podvezko, 2016). It considers the significance (impact) loss of each criterion, when one of other criteria obtains the optimal largest or smallest value.

For alternative ranking, 5 methods were used: VIKOR, TOPSIS, SAW, COPRAS and GRA. A short description of selected methods is given below.

The VIKOR method was developed as a multi-criteria decision-making method to solve a discrete decision problem with noncommensurable and conflicting criteria (Opricovic and Tzeng, 2004).

The TOPSIS method is based upon the concept that the chosen alternative should have the shortest distance from the ideal solution and the farthest from the negative-ideal solution (Hwang and Yoon, 1981).

The SAW method is one of the oldest, simplest and the most widely-used decision-making methods. This method is the basis of most MADM methods such as the PROMETHEE and AHP methods. Finding the weighted sum of the performance ratings for each alternative considering all attributes is the basic concept of the SAW method. (Taherdoost, 2023).

The COPRAS method was utilized to assess the superiority of one option over another and enables the comparison of options. The COPRAS technique systematically rates and assesses options based on their importance and utility level. This method is built on the premise of linear normalization, which allows for the direct comparison of diverse criteria by converting them into a common scale. Moreover, it incorporates the relative importance of each criterion into the decision-making process, enabling decision-makers to articulate and integrate their preferences and priorities into the analysis (Taherdoost, 2024).

The GRA method is quantitative and systematic approach, subsystem of grey system theory and most widely used in solving complex system (Patil et al, 2019). Grey System theory is focused on decision-making with partial information known and partial unknown. The information between known and unknown information is called as grey information (Patil et al, 2019).

A literary review of chosen approaches for determining criteria weights is given in Table 1, while the literary review for chosen methods for alternative ranking is in Table 2.

Table 1. Literary review of methods for determining criteria weight.

Method	Developed by	References
Analytic Hierarchy Process (AHP)	Saaty, T. L. (1970)	Saaty, 1970
		Saaty, 1980
		Saaty, 1987
		Vaidya & Kumar, 2006
Criteria Importance Through Interriteria Correlation (CRITIC)	Diakoulaki, D. Mavrotas, G. & Papayannakis, L. (1995)	Diakoulaki et al., 1995 Žižović et al., 2020 Krishnan et al., 2021
Criterion Impact Loss (CILOS)	Zavadskas, E. K. & Podvezko, V. (2016)	Zavadskas & Podvezko, 2016 Ayan, B. et al., 2023

Table 2. Literary review of methods for alternative ranking.

Method	Developed by	References
Višekriterijumska Optimizacija i Kompromisno Rešenje (VIKOR)	Opricovic, S. (1998)	Opricovic, 1998
		Opricovic & Tzeng, 2007
		Nikolić et al., 2010
Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)	Hwang, C.L. & Yoon, K.S. (1981)	Hwang & Yoon, 1981 Chakraborty, 2022
Simple Additive Weighting (SAW)	MacCrimmon, K.R. (1968)	MacCrimmon, 1968 Goodridge, 2016 Taherdoost, 2023
Complex Proportional Assessment (COPRAS)	Zavadskas, E. K., Kaklauskas, A. & Sarka, Z. (1994)	Zavadskas et al., 1994 Popovic et al., 2012 Taherdoost, 2024
Grey Relational Analysis (GRA)	Ju-Long, D. (1982)	Ju-Long (1982) Patil et al. (2019)

MATERIAL AND METHODS OF WORK

There are many software packages used for project management. Given the large number of software packages, the list of a few selected software packages was made. Software packages are selected based on previous papers involving project management software comparison (Cicibas et al., 2010; Manole & Avramescu, 2017; Milin et al., 2012; Milojević et al., 2023; Mitrović et al. 2011).

When making comparisons certain criteria were used, such as tasks (ability to create and follow tasks), resource management (ability to schedule, allocate and optimize resources), projects (ability to plan and follow progress of project) and data & analytics (ability to follow performance). Each criterion has its' subcriteria. In Table 3 and 4 comparative analysis of the software packages is shown.

Table 3. Comparative analysis of the project management software packages (<https://www.g2.com/>).

Group	Feature	ProjectManager.com	Microsoft Project	Wrike	Asana	BaseCamp
Resource Management	Scheduling	+	+			
	Definition	+	+			
	Allocation		+			
	Optimization		+			
Data & Analytics	Data Consolidation		+			
	Performance		+			

Table 4. Comparative analysis of the project management software packages (continuation)

Group	Feature	ProjectManager.com	Microsoft Project	Wrike	Asana	BaseCamp
Projects	Planning	+	+	+	+	+
	Project Map	+	+	+	+	
	Gantt	+	+			+
	Calendar View	+	+	+	+	+
	Views	+		+	+	+
	Templates				+	+
	Dashboards	+		+		+
Tasks	Baselining/KPIs					+
	Creation & Assignment	+	+	+	+	+
	Due Dates	+	+	+	+	+
	Task Prioritization	+	+	+	+	+
	To-Do Lists	+	+	+	+	+
	Dependencies	+	+	+	+	
	Mass Updates			+	+	
	Drag & Drop	+		+	+	+
	Recurring Tasks	+		+	+	

RESULTS AND DISCUSSION

In Table 5 decision matrix is presented. For simplicity and a better view of the table, criteria are presented as *C*, where: *C1* – Ease-of-use; *C2* – Customer support; *C3* – Value for money; *C4* – Functionality; *C5* – Price. Values for criteria Ease of use, Customer support, Value for money and Functionality are given on a scale from 1 to 5, where 1 depicts the lowest score and 5 the highest. Value for criterion Price is given based on the Premium/Pro package price, since every software offers multiple packages with different pricing. Alternatives are presented as *A*, where: *A1* – Microsoft Project; *A2* – Asana; *A3* – BaseCamp; *A4* – ProjectManager.com; *A5* – Wrike.

Table 5. Decision matrix (<https://www.softwareadvice.com/>).

	Ease of use [1-5]	Customer support [1-5]	Value for money [1-5]	Functionality [1-5]	Price [\$/user per month]
Criteria requirement	max	max	max	max	min
Microsoft Project	4.1	4.1	4.1	4.4	30
Asana	4.4	4.3	4.4	4.4	24.99
BaseCamp	4.3	4.3	4.2	4.2	15
ProjectManager.com	4	3.9	3.7	3.9	26
Wrike	4.1	4.3	4.2	4.3	25

First, it is necessary to determine criteria weights. Since the AHP method is subjective and requires input from the decision-maker. In Table 6 pairwise comparison matrix for AHP method is shown. Values are given based on the authors' preferences and Saaty's scale.

Table 6. Pairwise comparison matrix.

Criteria	<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>C5</i>
<i>C1</i>	1	5	2	3	7
<i>C2</i>	1/5	1	1/4	1/6	1
<i>C3</i>	1/2	4	1	2	4
<i>C4</i>	1/3	6	1/2	1	3
<i>C5</i>	1/7	1	1/4	1/3	1

The criteria weights that are obtained by the chosen approach are given in Table 7. It can be seen that for the AHP method, the most important criterion is Ease of use, yet the most important criterion for CRITIC and CILOS methods is Functionality. It can also be seen that the criteria weights for the CRITIC and CILOS methods are not the same. This can lead to different alternative rankings even when an alternative ranking method is the same.

Table 7. Criteria weights determent by the chosen methods.

	<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>C5</i>
AHP	0.431	0.060	0.255	0.194	0.060
CRITIC	0.16	0.15	0.12	0.25	0.32
CILOS	0.09	0.17	0.07	0.64	0.03

In Table 8 rank of the alternatives is given when criteria weights are determined by the AHP method. It can be seen that the ranking of alternatives using VIKOR, SAW and GRA methods is the same. Same can be seen when TOPSIS and COPRAS methods are used. In Figure 1 graphic representation of ranking is presented.

Table 8. Rank of the alternatives when criteria weights are determined by the AHP method.

$w_i = (0.431; 0.060; 0.255; 0.194; 0.060)$					
	VIKOR	TOPSIS	COPRAS	SAW	GRA
<i>A1</i>	4	4	4	4	4
<i>A2</i>	1	2	2	1	1
<i>A3</i>	2	1	1	2	2
<i>A4</i>	5	5	5	5	5
<i>A5</i>	3	3	3	3	3

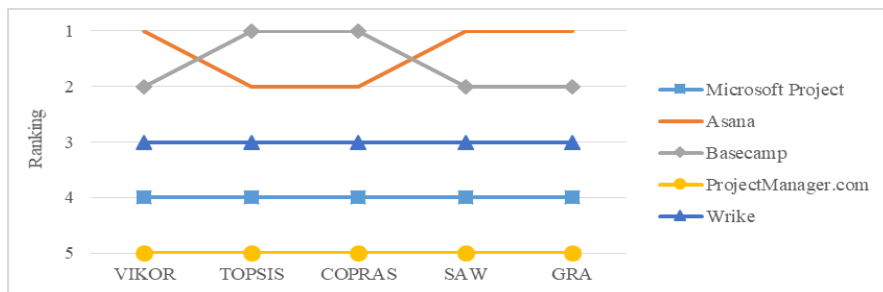


Figure 1. Software Ranking Comparison Using AHP-Derived Criteria Weights.

In Table 9 rank of the alternatives is given when criteria weights are determined by the CRITIC method. It can be seen that the ranking of alternatives using VIKOR, COPRAS and SAW methods is the same. It can also be seen that alternative ranking using TOPSIS and GRA methods differentiates from others. In Figure 2 graphic representation of ranking is presented.

Table 9. Rank of the alternatives when criteria weights are determined by the CRITIC method.

$w_i = (0.16; 0.15; 0.12; 0.25; 0.32)$					
	VIKOR	TOPSIS	COPRAS	SAW	GRA
<i>A1</i>	4	5	4	4	4
<i>A2</i>	2	2	2	2	1
<i>A3</i>	1	1	1	1	2
<i>A4</i>	5	4	5	5	5
<i>A5</i>	3	3	3	3	3

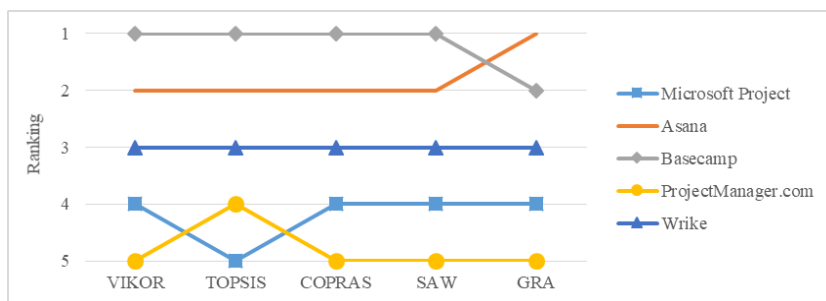


Figure 2. Software Ranking Comparison Using CRITIC-Derived Criteria Weights.

In Table 10 rank of the alternatives is given when criteria weights are determined by the CILOS method. It can be seen that the ranking of alternatives using VIKOR and TOPSIS methods is the same. It can be seen that alternative ranking using COPRAS, SAW and GRA methods differ from others. In Figure 3 graphic representation of ranking is presented.

Table 10. Rank of the alternatives when criteria weights are determined by the CILOS method.

$w_i = (0.09; 0.17; 0.07; 0.64; 0.03)$						
	VIKOR	TOPSIS	S	COPRA	SAW	GRA
A1	2	2		3	2	2
A2	1	1		1	1	1
A3	4	4		2	3	4
A4	5	5		5	5	5
A5	3	3		4	4	3

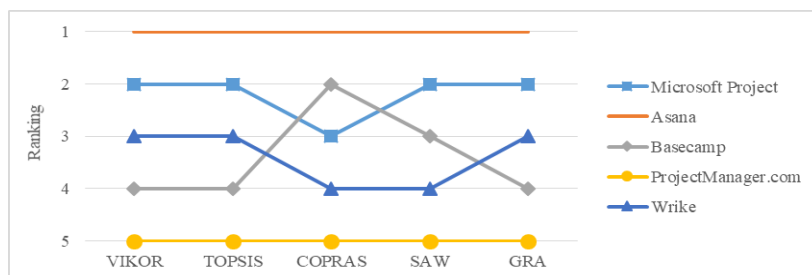


Figure 3. Software Ranking Comparison Using CILOS-Derived Criteria Weights.

As the previous tables demonstrate, alternative ranking methods yield varying results even when criteria weights are consistent. This discrepancy arises from the diverse normalization techniques and mathematical methodologies utilized.

CONCLUSIONS

This study demonstrates the significant impact of MCDM method selection on the ranking of alternatives in the context of project management software evaluation. MCDM methods are powerful tools for decision-making. Even though MCDM tends to be objective, they still need decision-maker input thus introducing subjectivity and affecting alternative ranking.

Different criteria weights are expected given the fact that we used three different approaches. From our perspective, the Analytic Hierarchy Process (AHP) method offers the most realistic weighting approach in this domain because it directly incorporates decision-maker preferences, rather than relying solely on mathematical ratios between criterion values.

Perišić, D., & Jovanović, J. (2025). Ranking of the software packages for project management using integrated MCDM methods. *STED Conference 14*(2), 61-69.

The lack of consensus in alternative rankings across these different weighting methods underscores a crucial point: there's no single "best" answer. Instead, the most robust solution emerges from a thorough comparison and synthesis of results.

Our findings indicate that Asana and Basecamp are overall best alternatives thus the best solution for the observed problem. Specifically, Asana and Basecamp share the first place when the criteria weights are determined using AHP method. Basecamp is considered overall best when the criteria weights are determined using CRITIC method, while Asana is the best alternative according to all methods used when the criteria weights are determined using CILOS method.

These results confirm the fact that MCDM methods provide invaluable insights into optimal alternatives based on given criteria. Still, it is advised that decision-makers make final decision using given information. As shown in the paper, different MCDM methods can give different rankings of alternatives. The choice of criteria weighting method significantly influences the final outcome.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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UTICAJ AKCIJSKIH PRODAJA NA PONAŠANJE POTROŠAČA

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SAŽETAK

Stalni napredak informacionih tehnologija milijarde potrošača svakim danom čini sve obrazovanijim i informisanijim o svemu, omogućavajući im tako daleko lakše donošenje odluke o kupovini. Dobra promocija značajno utiče na rast zainteresovanosti potrošača za određene proizvode i na direktan način utiče na potrošača da ostvari kupovinu.

Za marketing stručnjake posebno je zanimljivo ponašanje potrošača u procesu kupovine proizvoda gdje ih mogu kupiti po nižim, odnosno akcijskim cijenama. Rezultati brojnih do sada sprovedenih istraživanja pokazuju nam da se kupuju više proizvoda i usluga po akcijskim cijenama, a kao razlog tako povećane kupovine najčešće navode upravo isplativost kupovine.

Kupovina proizvoda istog kvaliteta, ali po nižoj i povoljnijoj cijeni drugi je po važnosti razlog kupovine proizvoda na akcijama moje organizuju prodavci.

Akcijske prodaje postaju poseban mamac za potrošače, pa se tada prodaju i oni proizvodi koji im u tom trenutku i nisu prijeko potrebni. Na taj način kupac smatra da je dobra odluka kupiti proizvod na akciji, bez obzira što ga neće odmah koristiti iz prostog razloga što tako uštedena sredstva može usmjeriti na kupovinu nekog drugog proizvoda ili usluge.

Ključne riječi: proizvod, marketing, promocija, potrošač, akcijska cijena.

AKCIJSKA PRODAJA

Mnogo je faktora koji manje ili više utiču na ponašanje potrošača u procesu kupovine. Ipak, najveći uticaj među faktorima imaju kulturni, društveni, lični i psihološki. (Milić, 2018)

Na kupovinu veliki uticaj imaju lični faktori s obzirom da lične karakteristike direktno utiču na ponašanje potrošača, a time i na proces donošenja odluke o kupovini. Kao lični faktori koji imaju poseban uticaj na ponašanje potrošača javljaju se: motiv i motivacija, percepcija, stavovi, obilježja ličnosti, vrijednosti i stil života i znanje. (Kesić, 2000)

U toku donošenja odluke o kupovini svaki potrošač raspolaže sa tri ograničena resursa, vremenom, novcem i sposobnošću prihvatanja i procesuiranja informacija. Pored ove ograničenosti potrošač mora uložiti poseban napor kako bi faktore uticaja iskoristio na najbolji mogući način i time kupovinu učinio uspješnom.

Poseban uticaj na proces donošenja odluke o kupovini imaju društveni faktori od kojih se izdvajaju: kultura, socijalizacija, društvo i društvene klase, društvene grupe, porodica i situacioni faktori.

Situacioni faktori su uglavnom vezani uz neku specifičnu situaciju, vrijeme, prostor i potpuno su nezavisni od obilježja potrošača, objekata i usluge koja se kupuje, kao što su: komunikacija, situacija korišćenja, fizičko i društveno okruženje, vrijeme kupovine i sl. (Rakić, Rakić, 2007)

Sve su to faktori koji utiču na kupovinu, a kad tome dodamo i prodaju proizvoda i usluga po cijenama nižim od cijena u redovnoj prodaji, onda se radio posebnim oblicima prodaje. Takva

posebna prodaja obuhvata, između ostalog, akcijsku prodaju, rasprodaju, sezonsko sniženje, prodaju proizvoda s greškom i prodaju proizvoda kojima ističe rok upotrebe. Prilikom obavljanja posebnog oblika prodaje trgovac je dužan istaći cijenu u redovnoj prodaji i cijenu tokom trajanja posebnog oblika prodaje

Zakon o zaštiti potrošača koji se primjenjuje od 2012. godine između ostalog tretira rasprodaju, akcijsku prodaju i prodaju robe sa nedostatkom.

Rasprodaja u smislu ovog zakona je prodaja robe po sniženoj cijeni u slučaju prestanka poslovanja trgovca, prestanka poslovanja u poslovnom objektu ili prestanka prodaje određenog proizvoda iz predmeta poslovanja trgovca, a sniženje je prodaja robe po sniženoj cijeni nakon proteka sezone ili prodaja proizvoda sa greškom, kao i prigodna sajamska prodaja u okviru sajamske priredbe, kao i stalna prodaja po sniženim cijenama u specijalizovanim prodajnim objektima, bez obzira na razlog sniženje cijena.

Proizvodi na akciji moraju biti jasno, vidljivo i čitljivo označeni riječima “akcija” ili “akcijska prodaja”. Pri oglašavanju akcijske prodaje trgovac je dužan navesti njeno trajanje, te je dužan istaći cijene u redovnoj prodaji i cijene tokom trajanja akcije.



Slika 1. Reklamni plakat najave rasprodaje (SportVision, 2025).

Figure 1. Sale announcement poster (SportVision, 2025).

Za razliku od rasprodaje, akcijska prodaja je prodaja određene količine proizvoda jednog proizvođača, u određeno vrijeme i na određenom mjestu, i to po cijeni koja je niža od cijene tog proizvoda ostvarene u redovnoj prodaji (Brkić, 2003).



Slika 2. Reklamni plakat akcijske prodaje (Sport Reality, 2025).

Figure 2. Promotional poster (Sport Reality, 2025).

Nedostatak na proizvodu postoji kada proizvod nema potrebna svojstva za redovnu upotrebu ili za naročitu upotrebu za koju je potrošač nabavlja, a koja je bila poznata trgovcu ili mu je morala biti poznata u vrijeme zaključenja ugovora, kada proizvod nije saobrazan uzorku, modelu ili opisu koji je dao trgovac, kada po kvalitetu i funkcionisanju ne odgovara onome što je uobičajeno kod proizvoda iste vrste i šta potrošač može da osnovano očekuje s obzirom na prirodu proizvoda i javna obećanja o posebnim svojstvima datim od trgovca.

Trgovac mora jasno, vidljivo i čitljivo na proizvodu ili na prodajnom mjestu označiti da je riječ o prodaji proizvoda s greškom, te upoznati potrošača u čemu se sastoji greška na proizvodu.



Slika 3. Reklamni plakat najave prodaje robe sa greškom (Legend, 2025).
Figure 3. Advertising poster announcing the sale of goods with an error (Legend, 2025).

Istraživanje uticaja akcijskih prodaja na ponašanje potrošača u kupovini

Cilj istraživanja bio je utvrditi u kojoj mjeri prodajne akcije, odnosno posebni oblici prodaje utiču na ponašanje kupaca, u sklopu istraživanja provedena je anketa s anketnim pitanjima dostavljenim putem e-maila. Anketa je provedena na području Republike Srpske od Prijedora do Trebinja na uzorku od 80 osoba, od čega 24 muškog i 56 ženskog pola.

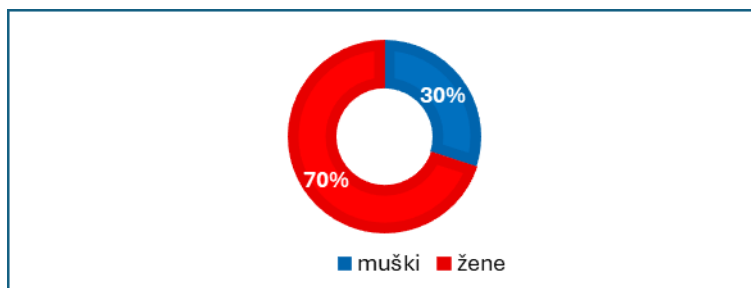
Anketni upitnik je koncipiran tako da dobijanjem odgovora spoznamo polnu, starosnu, finansijsku i obrazovnu struktura anketiranih kao i koliko akcije privlače kupce, da li i zašto kupuju na akcijama, te koji obim kupovine ostvaruju pri tome.

Anketni upitnik je sadržavao sledećih dvanaest pitanja:

- Struktura anketiranih po polu.
- Starosna struktura anketiranih.
- Finansijska struktura anketiranih.
- Obrazovna struktura.
- Koliko često kupujete?
- Kupujete li na akcijama?
- Pratite li akcije?
- Koliko vas privlači natpis akcija?
- Šta kupujete na akciji?
- Zašto kupujete na akciji?
- Podstiče li vas akcija na kupovinu?
- Kupujete li više na akciji, nego uobičajeno?

Struktura anketiranih po polu

Među anketiranim bilo je 24 muškog pola ili 30% anketiranih, dok je 56 anketiranih ili 70% bilo ženskog pola (Slika 4).

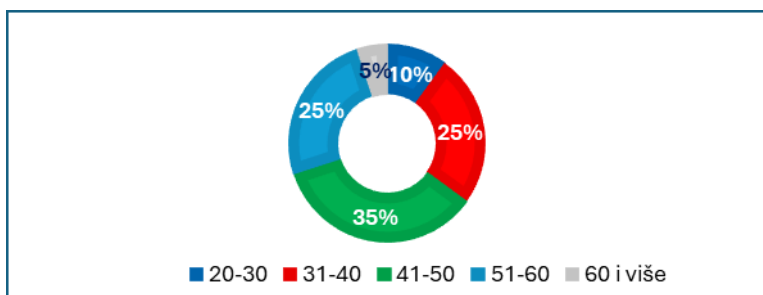


Slika 4. Polna struktura anketiranih.
Figure 4. Gender structure of the respondents.

Starosna struktura anketiranih

Od anketiranih najviše ili 35% bilo je onih starih između 41-50 godina, zatim slijede sa 25% anketirani starosti između 31-40 godina koliko je bilo il onih starosti između 51-60 godina.

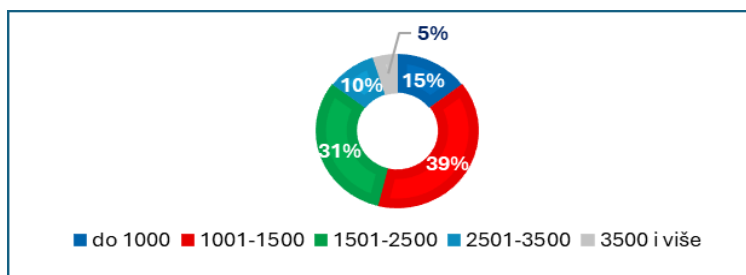
Anketiranih između 20-30 godina starosti bilo je 10%, a najmanje ili svega 5% je onih starijih preko 60 godina (Slika 5).



Slika 5. Starosna struktura anketiranih.
Figure 5. Age structure of the respondents.

Finansijska struktura anketiranih

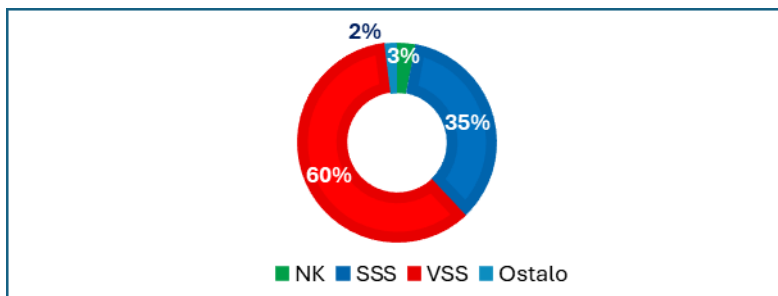
Blizu 40% anketiranih ima mjesečne prihode između 1.001-1.500 KM, 31% 1.501-2.500 KM, 15% do 1.000 KM, 10% od 2.501-3.500 i 5% ima prihode na mjesečnom nivou više od 3.500 KM. Najveći broj anketiranih ima prihode na mjesečnom nivou nešto veće od prosječnih primanja u Republici Srpskoj (Slika 6).



Slika 6. Finansijska struktura anketiranih.
Figure 6. Financial structure of the respondents.

Obrazovna struktura

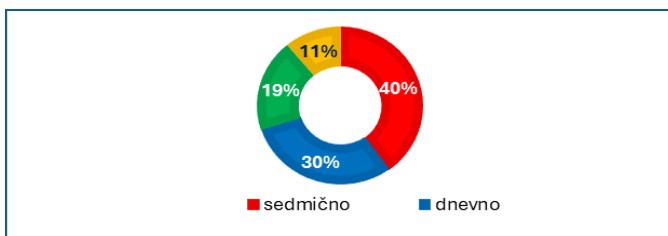
Među anketiranim 60% je sa VSS, 35% SSS, 2% NK, dok 3% anketiranih ima master ili doktorat (Slika 7).



Slika 7. Obrazovna struktura anketiranih.
Figure 7. Educational structure of the respondents.

Učestalost kupovine

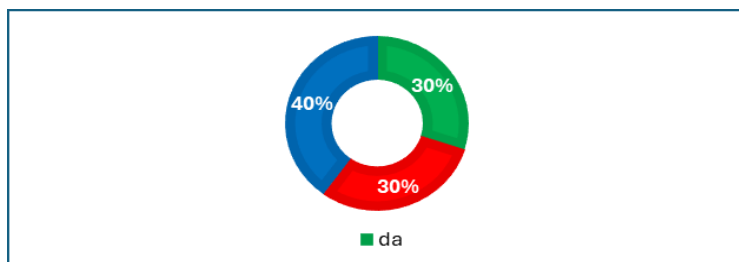
Anketiranjem smo željeli saznati koliko često anketirani idu u kupovinu. Na pitanje „Koliko često kupujete?“, 32 anketirana ili 40% kupuje sedmično, svaki dan kupuje 24 ili 30%, svaki drugi dan 15 ili 18,75%, a jednom mjesečno 9 ili 11,25% anketiranih. (Slika 8).



Slika 8. Učestalost kupovine.
Figure 8. Frequency of purchases.

Kupovina na akcijama

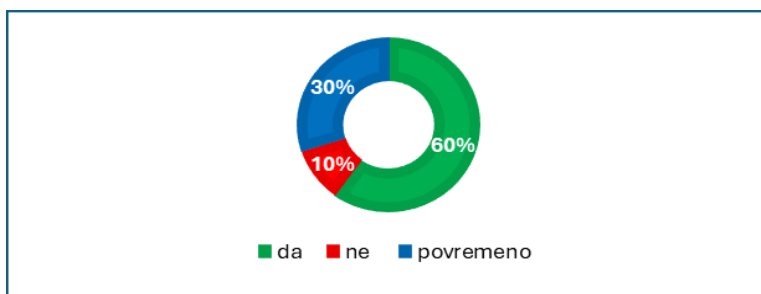
Na pitanje „Kupujete li na akcijama?“, sa da je odgovorilo 24 ili 30% anketiranih, isto toliko da ne kupuje, a 32 ili 40% je odgovorilo da na akcijama kupuje ponekad (Slika 9).



Slika 9. Kupovina na akcijama.
Figure 9. Buying shares.

Praćenje akcija

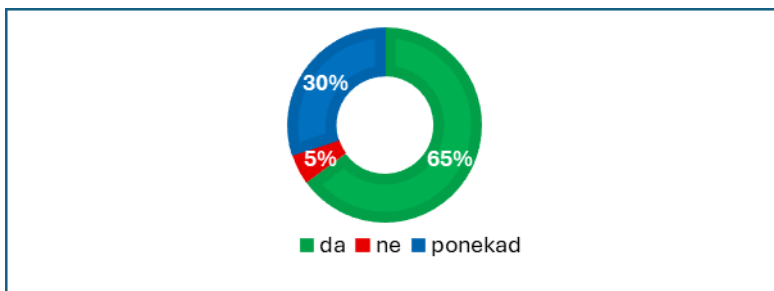
Akcije prati 48 ili 60% anketiranih, 8 ili 10% ne prati, dok 24 ili 30% povremeno prati akcije (Slika 10).



Slika 10. Praćenje akcija.
Figure 10. Action tracking.

Privlačenje pažnje natpisa akcija

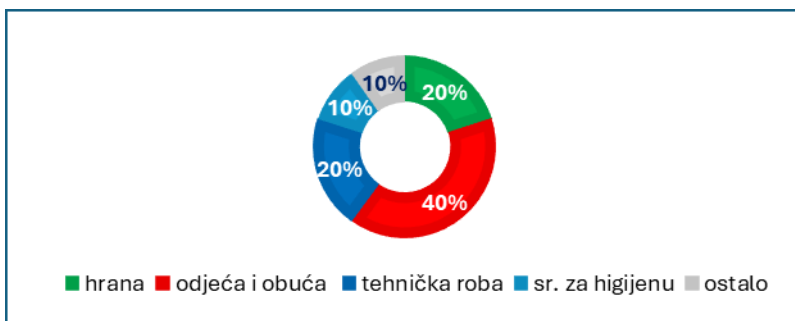
Natpis akcija privlači 52 ili 65% anketiranih, 24 ili 30% povremeno, a 4 ili 5% uopšte ne registruje natpis akcija. (Slika 11)



Slika 11. Privlačenje pažnje natpisa akcija.
Figure 11. Attention-grabbing action captions.

Struktura kupovine na akciji

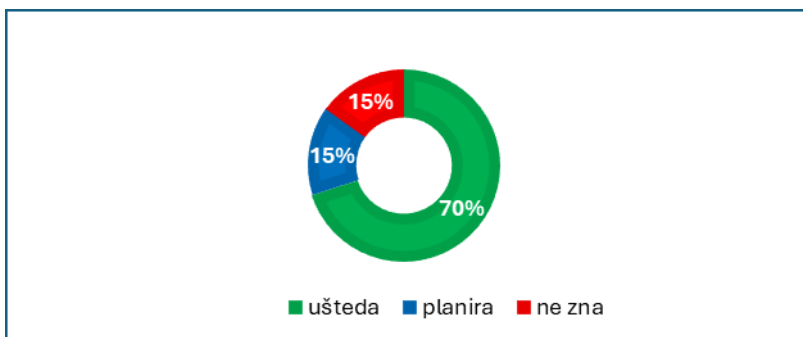
Da na akciji kupuje hranu odgovorilo je 16 ili 20%, odjeću i obuću 32 ili 40%, tehničku robu 16 ili 20%, sredstva za ličnu higijenu 8 ili 10% i ostalu robu 8 ili 10% (Slika 12).



Slika 12. Struktura proizvoda kupljenih na akciji.
Figure 12. Structure of products purchased on sale.

Razlog kupovine na akciji

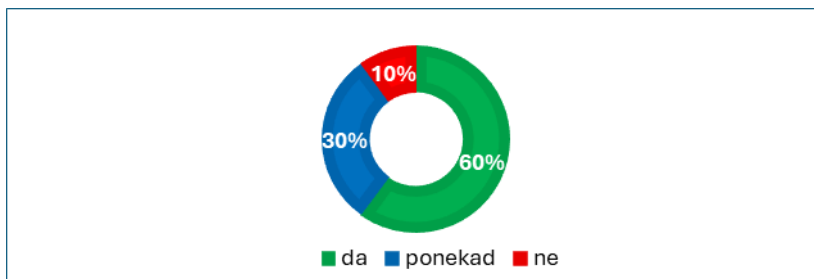
Prvenstveno radi uštede na akciji kupuje 56 ili 70% anketiranih, jer su planirali 12 ili 15%, a ne zna ih isto toliko (Slika 13).



Slika 13. Razlog kupovine na akciji.
Figure 13. Reason for buying on sale.

Uticaj akcije na kupovine

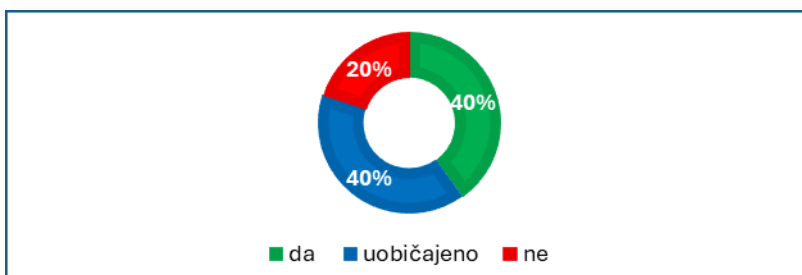
Na kupovinu akcija podstiče 48 ili 60% anketiranih, 24 ili 30% ponekad, dok akcija ne podstiče na kupovinu 8 ili 10% anketiranih (Slika 14).



Slika 14. Uticaj akcije na kupovinu.
Figure 14. Impact of the action on purchases.

Obim kupovine na akciji

Više nego uobičajeno na akciji kupuje 32 ili 40%, isto toliko uobičajeno, dok 16 ili 20% ne kupuje više nego inače (Slika 15).



Slika 15. Obim kupovine na akciji.
Figure 15. Volume of purchases on the action.

Analizom provedene ankete zaključujemo da je na uzorku anketiranih većina ženskog pola i to u dobi između 41-50 godina, što znači da je većina porodična i da vode računa o kućnom budžetu s obzirom na primanja koja imaju. Najveći procenat je onih sa visokom stručnom spremom čak 60% što se podudara i sa činjenicom da imaju prosječna primanja nešto veća u odnosu na prosječnu platu u Republici Srpskoj.

Obzirom da je 70% anketiranih ženskog pola većina ih vodi brigu o tome da pojedine stvari kupuju svaki dan, a veću kupovinu odnosno njih 40% obavljaju jednom sedmično. Upravo zbog vođenja brige oko kućnog budžeta većina ih vodi brigu o tome kada su prodajne akcije u trgovinama i kada na istima mogu kupiti proizvode koji su im od značajne važnosti poput odjeće i obuće, prehrambenih proizvoda, jer se ti proizvodi u porodici najčešće kupuju. Danas u XXI vijeku informacije o akcijama anketirani dobijaju iz različitih izvora, putem medija, prospekata i bilborda. Akcije pospješuju većinu potrošača da kupe i više nego uobičajeno proizvoda, pa i onih koji im u tom trenutku i nisu neophodni iz prostog razloga što anketirani smatraju da na taj način dodatno štede, jer će im ti proizvodi svakako trebati u narednom periodu.

Imajući u vidu naprijed navedeno iz provedene ankete u ovom istraživanju nameće se i odgovor da većina anketiranih prati prodajne akcije.

Pripadnice ženskog pola su u najvećem broju ispunjavale anketni upitnik sa prosjekom godina koji nam ukazuje da najveći broj njih imaju svoju porodicu. Može se reći da reakcije i ponašanje anketiranih kupaca imaju širok prostor za detaljnije istraživanje i analizu koje bi uključivalo relativno veći obuhvat anketiranih nego što je bio slučaj u ovom istraživanju. Obuhvatanjem većeg broja anketiranih u kojoj bi pored zaposlenih bile zastupljene i ostale starosne i statusne grupe kao što su nezaposleni, studenti i penzioneri, čija su prosječna primanja na mjesečnom nivou niža od anketiranih, sasvim sigurno da bi rezultati bili nešto drugačiji i vjerodostojniji u odnosu na rezultate dobijene ovim istraživanjem.

Gotovo je nemoguće danas ući u bilo koju trgovinu ili web portal organizacije iz sektora trgovine i ne primijetiti kako se na različite načine oglašavaju i pozivaju nas na kupovinu po akcijskim cijenama. Ovo rade prvenstveno iz razloga što žele prodati što više sa zaliha određenih proizvoda, ali na taj način i privući kupce da kupuju nove proizvode koji tek trebaju dobiti svoje potrošače. Tako smo danas sve češće svjedoci da se organizuju akcije i na potpuno nove proizvode i nove kolekcije gdje trgovci oglašavaju da kupovinom proizvoda iz nove kolekcije drugi proizvod dobijate u pola cijene. Nisu rijetke situacije da se proizvodi iz nove kolekcije, novi modeli prodaju na akciji u ograničenom vremenskom trajanju, a sve u cilju da bi se privukli potencijalni kupci da ih isprobaju i kasnije kupuju i po redovnim cijenama, dakle bez popusta. Pored vidno istaknutih natpisa za akcijskim cijenama, potencijalnim kupcima se sa centralnog razglasa pušta i opuštajuća muzika kako bi se što lakše opredijelili za kupovinu. Ta opuštajuća muzika često je i podloga za umilni ženski glas koji vas obavještava da je u toku akcija na određeni proizvod koji još samo danas možete kupiti po akcijskoj cijeni. Iako su kupci koncentrisani na kupovinu i s posebnom pažnjom razgledaju ponuđene proizvode slušajući opuštajuću muziku svakako da im ne može promaći ni ono što im umilni ženski glas oglašava putem razglasa.

ZAKLJUČCI

Na ponašanje potrošača pri kupovini proizvoda ili usluga utiču unutrašnji i spoljašnji faktori, odnosno lični, društveni i psihološki. Ponašanje potrošača definišemo kao lično ponašanje koje potrošač pokazuje pri istraživanju, kupovini, korištenju, ocjeni i raspoređivanju proizvoda i usluga čijom kupovinom očekuje da će zadovoljiti prvenstveno svoje potrebe. Identifikovanje učesnika u procesu kupovine uz njegovo precizno i kontinuirano praćenje može imati veliki značaj za konačan uspjeh organizacije, a to je maksimalno zadovoljstvo kupca uz ostvarenje profita. Danas se kroz proučavanje ponašanja potrošača istražuje kako potrošač donosi odluku o potrošnji novca, vremena i energije kojima raspolaže na kupovinu određenih proizvoda ili usluga.

Stručnjaci koji se bave marketingom i pored svih informacionih, komunikacionih i tehnoloških napredaka još uvijek većinu faktora koji imaju uticaj na ponašanje potrošača ne mogu kontrolisati u potpunosti. Stalnim istraživanjem, analizama i korištenjem znanja koji su prikupili, marketing stručnjaci nastoje što više uskladiti proizvode i usluge sa željama i krajnjim ciljevima potrošača. Trend stalnog istraživanja potrošača raste iz prostog razloga što se na taj način sve više dolazi do saznanja o njihovom ponašanju prilikom kupovine proizvoda ili usluga.

Stalni napredak informacionih tehnologija milijarde potrošača svakim danom čini sve obrazovanijim i informisanijim o svemu što se događa i nudi na tržištu omogućavajući im tako daleko lakše donošenje odluke o kupovini. Svaki potrošač je individua za sebe i njegovo ponašanje pod uticajem različitih marketing faktora podložno je manjim ili većim promjenama. Dobra promocija je ta koja ima značajan uticaj na rast zainteresovanosti potrošača za određene proizvode i ona na direktan način privlači i utiče na potrošača da ostvari kupovinu.

Za marketing stručnjake posebno je zanimljivo kako se potrošači ponašaju u procesu kupovine proizvoda i usluga u posebnim oblicima prodaje gdje određene proizvode mogu kupiti po posebno određenim nižim, odnosno akcijskim cijenama. Rezultati brojnih do sada sprovedenih istraživanja pokazuju nam da učesnici anketa kupuju više proizvoda i usluga na posebnim akcijama po sniženim cijenama, a kao razlog tako povećane kupovine najčešće navode upravo isplativost kupovine.

Kupovina proizvoda istog kvaliteta, ali po nižoj i povoljnijoj cijeni drugi je po važnosti razlog kupovine proizvoda na akcijama koje organizuju prodavci. Takođe, potrošači praćenjem akcija i kupovinom proizvoda na istima ostvaruju značajne uštede kupujući po povoljnijim cijenama proizvod koji je inače u redovnoj prodaji znatno skuplji. Na praćenje akcija i povećan obim kupovine na istima utiče i opšta ekonomska situacija u državi, stalni rast cijena i stagniranje životnog standard, tako da se dobar dio anketiranih sve više prilikom kupovine odlučuje upravo na one proizvode po nižim i povoljnijim, odnosno akcijskim cijenama.

Rezultati provedenog ispitivanja pokazuju nam poseban značaj akcijskih prodaja na ponašanje kupaca. Obzirom na ograničenu finansijsku moć potrošača, dobar dio anketiranih naročito iz nižeg i srednjeg sloja kupovne moći kupuje upravo na akcijskim prodajama, jer tada

Milić, M. et al. (2025). Uticaj akcijskih prodaja na ponašanje potrošača. *STED Conference 14*(2), 71-80.

mogu kupiti proizvode koje najčešće koriste oni i članovi njihove porodice po nižim i povoljnijim cijenama.

Akcijske prodaje toliko su zastupljene danas, tako da su one praktično svakodnevne. Gotovo je nezamislivo da u bilo kom prodajnom objektu kao što je npr. Tropic, Idea, Kort, Fortuna, Bingaoa, Lidl, SportVision, SportReality, Buzz, Juventa, Intersport ili bilo koji drugi prodavac tehničke robe, odjeće, obuće, pa i auto salona nemamo svakodnevno prodaju po akcijskim cijenama jednog ili više proizvoda. Tako akcijske prodaje postaju poseban mamac za potrošače, pa se tada prodaju i oni proizvodi koji im u tom trenutku i nisu prijeko potrebni. Na taj način kupac smatra da je dobra odluka kupiti proizvod na akciji, bez obzira što ga neće odmah koristiti iz prostog razloga što tako uštedena sredstva može usmjeriti na kupovinu nekog drugog proizvoda ili usluge. Na samom kraju bitno je napomenuti da u svim akcijskim prodajama proizvoda po sniženim cijenama u velikim trgovinskim lancima obavezu učešća pored prodavaca imaju i proizvođači, odnosno dobavljači odričući se dijela svoje marže i zarade.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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THE IMPACT OF PROMOTIONAL SALES ON CONSUMER BEHAVIOR

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ABSTRACT

The constant advancement of information technology is making billions of consumers more educated and informed about everything every day, making it far easier for them to make purchasing decisions. Good promotion significantly affects the growth of consumer interest in certain products and directly influences the consumer to make a purchase.

For marketing experts, the behavior of consumers in the process of purchasing products where they can buy them at lower, or promotional prices, is particularly interesting. The results of numerous surveys carried out so far show us that more products and services are bought at promotional prices, and the reason for such increased purchases is most often given by the profitability of the purchase.

Buying products of the same quality, but at a lower and more favorable price, is the second most important reason for buying products at events organized by sellers.

Promotional sales become a special lure for consumers, so those products that they don't really need at that moment are also sold. In this way, the customer thinks that it is a good decision to buy a product on sale, regardless of the fact that he will not use it immediately for the simple reason that he can direct the funds thus saved to the purchase of another product or service.

Keywords: product, marketing, promotion, consumer, promotional price.

AI IN IT BUSINESS: PERCEPTIONS OF SERBIAN IT PROFESSIONALS ON THE IMPACT OF ARTIFICIAL INTELLIGENCE ON INDIVIDUAL PRODUCTIVITY

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ABSTRACT

This paper explores the perceptions of Serbian IT professionals regarding the impact of artificial intelligence (AI) tools on individual productivity in the context of IT business. As AI technologies become increasingly integrated into everyday work environments, particularly in knowledge-intensive industries, understanding user attitudes and experiences is essential. The research is based on a quantitative study conducted through an online questionnaire, which gathered responses from IT professionals working in various roles across Serbia. The questionnaire assessed the frequency of AI tool usage, perceived benefits and challenges, and self-reported changes in work efficiency. The results indicate a generally positive perception of AI tools, especially in relation to time-saving and task automation. This study contributes to a better understanding of how AI adoption is shaping modern IT workflows and provides insights relevant to business leaders and digital entrepreneurs in the tech industry.

Keywords: artificial intelligence, IT professionals, IT business, business applications, job productivity.

INTRODUCTION

Artificial intelligence (AI) is recognized as one of the fastest-growing fields, attracting increasing attention in everyday and business life. It is a form of intelligence similar to human intelligence, demonstrated by machines in solving problems of various kinds (Aldoseri et al., 2023). The goal of AI technology is to develop systems capable of perceiving, learning, planning, predicting, and making decisions in ways that resemble human thinking (Ayinaddis, 2025; Xu, et al., 2021; Enholm et al., 2022; Zohuri & Moghaddam, 2020). Using self-learning systems and technologies such as machine learning, natural language processing, robotics, and computer vision, AI impacts many areas of human activity (Qudus, 2025; Aldoseri et al. 2023; Xu, et al. 2021; Palanivelu & Vasanthi, 2020). These technologies provide significant advantages over human intelligence, including scalability, cost efficiency, consistency, and reduced errors, making AI a central driver of change in society and the economy (Alenezi & Akour, 2025; Palanivelu & Vasanthi, 2020).

The implementation of AI in business and industrial processes has transformed knowledge-based work. In the IT sector, where tasks are often complex, data-intensive, and time-consuming, AI enhances productivity by supporting developers, analysts, and IT professionals in decision-making, code generation, bug detection, workflow optimization, and software testing (Alenezi & Akour, 2025; Ayinaddis, 2025; Qudus, 2025; Xu et al., 2021). Generative AI systems, such as ChatGPT, are extending this influence to industries beyond software. These systems improve performance and problem-solving across areas including customer service, healthcare, transport, finance and education, while also contributing to the development of industry and whole society (Rane, 2023). Furthermore, AI assists in material innovation, project scheduling, safety management, and quality control, demonstrating its broad applicability (Xu et al., 2021).

Despite the growing adoption of AI technologies in the IT industry, organizations often face

Radosavljević, N. et al. (2025). AI in IT business: perceptions of Serbian IT professionals on the impact of artificial intelligence on individual productivity. *STED Conference 14*(2), 81-88.

challenges in fully exploiting their potential. Challenges include integrating AI into existing processes, managing diverse data sources, and connecting knowledge across different domains (Enholm et al., 2022;). Particularly in IT, a major challenge lies in understanding how employees actually use AI tools and how value is generated through their application. Recognizing these organizational challenges, alongside the awareness, reflection, and perception of IT professionals, is essential to fully harness the productivity benefits AI can offer (Kerzel, 2021).

The national framework for AI development in Serbia is defined by the Strategy for the Development of Artificial Intelligence 2020–2025 (Government of the Republic of Serbia, 2019). The strategy emphasizes the role of AI as a driver of economic growth, innovation, and improved public services, while also addressing the need for ethical and responsible use of these technologies. Key objectives include improving innovation capacities, supporting the digital transformation of businesses, and fostering the development of human capital by strengthening AI-related skills. In this context, the perceptions and experiences of IT professionals are particularly relevant, as they represent the workforce most directly involved in AI adoption and implementation in practice.

While the adoption of AI in Serbian companies remains limited—only 34% of firms report having experience with artificial intelligence, mainly in ICT and technical services sectors (ICT Hub, 2024)—the perspective of individual IT professionals provides a more dynamic picture. As organizational strategies are still evolving, professionals may be at the forefront of experimenting with AI tools in their daily work.

Beyond technical considerations, IT professionals also face human and organizational challenges, such as balancing automation with human oversight, developing new skills required for AI-driven work, and addressing ethical dilemmas, including model biases and data confidentiality. Research focused on IT specialists' perceptions and experiences with AI is increasingly important, as the human factor largely determines whether technology genuinely improves productivity and work quality (Alenezi & Akour, 2025). Kassa and Worku (2025) emphasize that full integration of AI into work processes requires not only understanding technical and organizational aspects, but also considering employees' perceptions of the usefulness of AI tools and their reflections on the impact on daily tasks. Zhao and colleagues (2025) investigated how employees' awareness of AI influences their job performance, including extra-role tasks, and how perceived overqualification and collaboration with AI shape these outcomes. Laxmi & Leela (2023) examined how employees in IT companies perceive AI use and its impact on their performance in dynamic work environments.

According to the literature, the human factor determines whether technology genuinely increases productivity, as value is created through the way people use AI tools in an organizational context. This study examines the perceptions of IT professionals in Serbia regarding AI usage, the usefulness of AI tools, and their awareness of AI applications in relation to work efficiency.

AI awareness refers to how employees perceive and understand the potential impact of AI technologies on their future careers. It includes both - positive aspects, such as new opportunities and possibilities for personal and professional growth, as well as concerns, such as the risk of job replacement by AI (Zhao et al., 2025). Reflection on artificial intelligence refers to employees' consideration of how AI impacts their work helping them to make decisions, improving their creative abilities, and helping them with routine tasks, contributing to productivity and efficiency within the organization (Laxmi & Leela, 2023). Perceived usefulness of AI tools refers to employees' perception of how AI tools can support their work, improve efficiency, and contribute to better performance (Zhao et al., 2025).

Based on the literature and identified research gaps, the following hypotheses are proposed:

H1: A higher level of reflection on AI use positively influences the job performance of IT professionals in Serbia.

H2: A higher level of awareness of AI positively influences the job performance of IT professionals in Serbia.

H3: A positive perception of the usefulness of AI tools positively influences the job performance of IT professionals in Serbia.

The study is structured around the conceptual model presented in Figure 1, which connects Reflection on AI Usage, AI Awareness, and Perceived Usefulness of AI Tools with Employee Performance. The model illustrates the hypothesized relationships between these constructs and provides a visual framework for testing the proposed hypotheses (H1–H3). By presenting this model, the study highlights the central role of engagement with AI in shaping individual productivity outcomes of IT professionals.

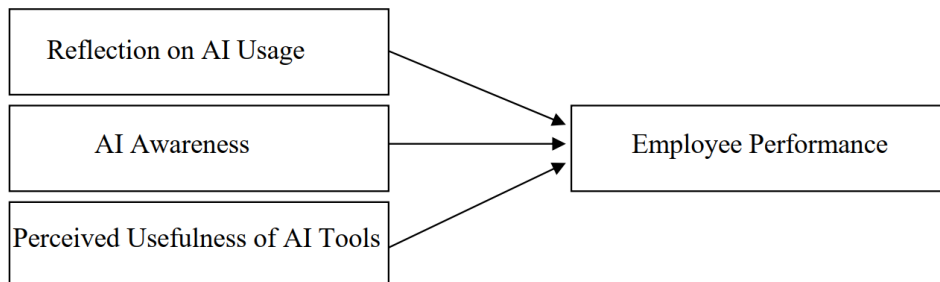


Figure 4. Conceptual model linking Reflection on AI Usage, AI Awareness, and Perceived Usefulness of AI Tools with Employee Performance.

MATERIAL AND METHODS OF WORK

The main objective of this study was to examine the perceptions of IT professionals in Serbia regarding the impact of AI on individual productivity in the business environment. For the purposes of the research, an adapted questionnaire was developed and consisted of 29 questions divided into five main sections.

All sections of the questionnaire were adapted from previous studies to ensure reliability and relevance for examining AI perceptions among Serbian IT professionals. The first section measured Reflection on AI Usage with six items from Zhao et al. (2025), slightly modified for the IT work context. AI awareness was assessed using four items from the same author. The Perceived Usefulness of AI Tools scale was adapted from Laxmi and Leela (2023) and consisted of seven items, while the Employee Performance (efficiency) scale from the same study included six items. All adaptations preserved the key concepts of the original instruments while ensuring applicability to the local context.

Participants responded on a 5-point Likert scale, where 1 represented “strongly disagree” and 5 “strongly agree.” The questionnaire also collected demographic and professional data, including gender, age, education, years of experience in IT, and current job position. In the final item, respondents reported the AI tools they most frequently use.

The questionnaire was distributed electronically via LinkedIn and through private messages sent to contacts within professional IT networks. A total of 87 valid responses were collected during the data collection period, which spanned from April to June 2025. The collected data were systematically processed and analyzed using SPSS software. Preliminary analyses included descriptive statistics to summarize the characteristics of the sample, reliability testing using Cronbach’s alpha to ensure the internal consistency of the adapted scales, and regression analysis to examine the relationships between AI awareness, perceived usefulness of AI tools, and self-reported productivity.

The sample consisted of 58 men and 29 women. The majority of respondents hold a Master’s degree in academic studies (35.6%), followed closely by those with a Bachelor’s degree in academic studies (32.2%). A smaller proportion of participants have a Bachelor’s degree in applied studies (13.8%), while the remaining respondents have a high school diploma (5.7%), a Master’s in applied studies (3.4%), or a Doctorate (9.2%).

The largest group of respondents are mid-level professionals with 4–6 years of experience, representing 31% of the sample. Junior-level employees with 1–3 years of experience make up 25.3%, while entry-level and senior-level participants each constitute 16.1%, and those with over 10 years of experience make up 11.5% of the total. A total of 58% of respondents belong to the

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26–35 age group, while only 20% of participants are older than 36 years. The largest share of respondents works as Programmers/Software Developers, accounting for 51.7% of the sample. This is followed by System Administrators/System Engineers at 19.5%, Project Managers/Scrum Masters at 10.3%, Data Analysts/Data Scientists at 9.2%, while QA/Testers and DevOps/Cloud Engineers each represent 4.6% of the respondents.

RESULTS AND DISCUSSION

Reliability analysis for all variables was conducted using Cronbach's alpha coefficient. The results of the reliability analysis are presented in Table 1. The reliability of the measurement scales, as a key prerequisite for further statistical analysis, was assessed using Cronbach's alpha coefficient. Nunnally (1978) states that a scale can be considered reliable when the Cronbach's alpha value is at least 0.70. All measurement scales used in this study achieved high reliability coefficients. The most reliable scale was for Employee Performance ($\alpha_{EP} = 0.908$), while AI Awareness showed the lowest reliability ($\alpha_{Aw} = 0.776$).

The normality of the data distribution was assessed using skewness and kurtosis values, along with the Kolmogorov–Smirnov test (Table 1). The results indicate that the variables Perceived Usefulness of AI Tools (PU) and AI Awareness (Aw) exhibited only minor deviations from normality, suggesting that their distributions are approximately symmetric and not heavily peaked. In contrast, Reflection on AI Usage (RU) and Employee Performance (EP) showed substantial deviations from normality, with significant negative skewness and high kurtosis values, as confirmed by the Kolmogorov–Smirnov test ($p < 0.001$). These findings suggest that the data for RU and EP are not normally distributed, and therefore, non-parametric statistical techniques were employed in all subsequent analyses.

Table1. Results of reliability and descriptive analysis and normality tests.

Variable	Cronbach's alpha	Mean	Std. deviation	Skewness	Kurtosis	Kolmogorov-Smirnov (N=87)	
						K-S	p-value
Perceived Usefulness of AI Tools (PU)	0.884	3.343	0.9887	-0.378	-0.355	0.075	0.200*
AI Awareness (Aw)	0.776	3.203	1.0655	-0.260	-0.559	0.091	0.072
Reflection on AI Usage (RU)	0.913	4.007	0.9268	-1.687	2.967	0.173	0.000
Employee Performance (EP)	0.908	4.374	0.769	-2.065	6.663	0.208	0.000

*Lilliefors Significance Correction

The mean scores indicate that participants perceive AI tools as moderately useful ($M_{PU} = 3.34$, $SD_{PU} = 0.99$) and have moderate AI awareness ($M_{Aw} = 3.20$, $SD_{Aw} = 1.07$). Engagement with AI in their work ($M_{RU} = 4.01$, $SD_{RU} = 0.93$) and Employee Performance ($M_{EP} = 4.37$, $SD_{EP} = 0.77$) are higher, suggesting frequent use of AI and relatively high self-rated performance.

Table 2 presents the Spearman's rho correlation coefficients between the analyzed variables. The results show a strong positive correlation between PU and Aw ($\rho = 0.666$, $p < 0.001$), indicating that higher perception of usefulness is associated with greater awareness. PU was also moderately positively correlated with RU ($\rho = 0.318$, $p = 0.003$), while Aw showed a similar positive correlation with RU ($\rho = 0.305$, $p = 0.004$). Aw, however, was negatively correlated with EP ($\rho = -0.223$, $p = 0.038$), suggesting that greater awareness does not necessarily translate into higher performance. RU demonstrated a moderate positive correlation with EP ($\rho = 0.367$, $p < 0.001$), whereas PU was not significantly related to EP ($\rho = -0.079$, $p = 0.468$).

Table 2. Correlation analysis

Variable	PU	Aw	RU	EP
Perceived Usefulness of AI Tools (PU)	1			
AI Awareness (Aw)	0.666**	1		
Reflection on AI Usage (RU)	0.318**	0.305**	1	
Employee Performance (EP)	-0.079	-0.223*	0.367**	1

* $p < 0.05$, ** $p < 0.01$

The multiple regression analysis was performed to examine the impact of PU, Aw, and RU on EP. Despite minor deviations from normality for some variables, the sample size ($N = 87$) is sufficient for regression, and linear relationships were supported by correlation analysis. Multicollinearity among predictors was tested. Tolerance values ranged from 0.47 to 0.74, while VIF values were between 1.34 and 2.09. Since all Tolerance values are above the recommended threshold of 0.20, and all VIF values are below 5, it can be concluded that there are no multicollinearity issues in the model.

The overall model was statistically significant, $F(3, 87) = 11.603$, $p < 0.001$, explaining 29.5% of the variance in EP ($R^2 = 0.295$, Adjusted $R^2 = 0.270$). The coefficients show that:

- PU had a positive but non-significant effect on EP ($\beta = 0.177$, $t = 1.417$, $p = 0.160$).
- Aw had a significant negative effect on EP ($\beta = -0.403$, $t = -3.030$, $p = 0.003$).
- RU had a significant positive effect on EP ($\beta = 0.597$, $t = 5.591$, $p < 0.001$).

These findings indicate that Reflection on AI Usage is the strongest positive predictor of employee performance, while Awareness of AI negatively affects performance. Perceived Usefulness, although positively related, does not significantly influence EP in this model.

Table 3. Multiple linear regression analysis

Variable	B	Standard Error	Beta	t	Sign. (p)
Constant	2.858	0.341	-	8.386	0.000
PU	0.138	0.097	0.177	1.417	0.160
Aw	-0.291	0.096	-0.403	-3.030	0.003
RU	0.496	0.089	0.597	5.591	0.000

Dependent Variable: Employee Performance, $R^2 = 0.295$; $F = 11.603$; Sig = 0.001, $N = 87$

* $p < 0.05$, ** $p < 0.01$

The results of this research can be compared with previous studies. While Laxmi and Leela (2023) showed that AI mostly has a positive impact on employees' work performance, our findings indicate that the situation may be more complex. Specifically, Aw can sometimes create a sense of overqualification and negatively affect performance, but through reflection on its use and collaboration with AI, better outcomes can be achieved. These conclusions align with more recent studies (Zhao et al. 2025), emphasizing that the impact of AI is not one-sided, but depends on how employees perceive and apply these technologies.

The analysis of responses from IT professionals in Serbia shows that ChatGPT is the most frequently used AI tool, mentioned by approximately 62% of participants. This highlights its wide application in various tasks, from content generation and client communication to coding support and data analysis. Microsoft Copilot and GitHub Copilot were also commonly used, with usage rates of around 18% and 9%, respectively, reflecting their importance in software development and programming tasks. Other tools such as DeepSeek, Gemini, and Grok were used less frequently, with adoption rates between 5–7%, while Grammarly and Claude had limited use, mainly for writing, proofreading, or UI prototyping. Tools like DALL·E, Gamma, and TabnineAI were not

reported in this sample, indicating lower popularity among IT professionals in Serbia. Overall, these results indicate that IT professionals predominantly rely on AI tools for text generation, coding assistance, and task automation, while specialized tools are used selectively. ChatGPT clearly serves as the central tool in daily work, complemented by other AI applications for specific functions.

CONCLUSIONS

This study provides an initial exploration of how AI-related factors influence perceived job performance among IT professionals in Serbia. The results show that reflective engagement with AI tools (RU) is the strongest positive predictor of employee performance, suggesting that employees who actively consider how AI can support their tasks, improve decision-making, and reduce routine workloads achieve higher efficiency. These findings are consistent with prior experimental evidence showing that generative AI improves both the speed and quality of professional work (Noy & Zhang, 2023; Brynjolfsson, Li, & Raymond, 2023). In contrast, AI awareness (Aw was negatively associated with performance), suggesting that simple awareness of AI's potential may not translate into improved productivity and could even create a sense of overqualification or hesitation. Perceived usefulness of AI tools (PU) demonstrated a positive but non-significant relationship with performance, implying that subjective evaluations of utility are insufficient without reflective application.

These findings highlight the importance of cognitive and behavioral engagement with AI, beyond simple exposure or awareness. Organizations should therefore not only provide AI tools, but also foster reflective practices, such as training programs, guided use-cases, and collaborative experimentation, to enable employees to fully harness AI's potential. The results also underline the complex nature of AI integration: its impact depends largely on how employees perceive, interpret, and actively utilize the technology in their daily work routines.

The findings also have practical implications for IT managers and organizations. Reflection on AI usage proved to be the strongest predictor of employee performance, suggesting that companies should not only invest in AI tools, but also create training programs and guidelines that encourage employees to critically reflect on their use. Furthermore, the negative effect of AI awareness indicates that awareness campaigns alone are not sufficient and may even discourage productivity if not accompanied by practical skill-building. Finally, the results highlight the need for better alignment between individual-level adoption of AI tools and broader organizational strategies, in order to fully realize the productivity benefits of artificial intelligence in the IT sector.

For IT managers, these insights suggest that successful AI deployment requires attention to organizational culture, employee engagement, and reflective practices, in addition to technical implementation. Future research could expand on these findings by exploring team-level interactions with AI, or investigating sector-specific AI applications to provide a more comprehensive picture of AI's influence on productivity.

This study has some limitations that should be considered. The sample size (N = 87) is relatively small and may not fully represent the diversity of IT professionals in Serbia. Consequently, the generalizability of the results to other contexts or countries may be limited. Future studies could include larger and more heterogeneous samples to enhance external validity.

The data were collected through self-reported questionnaires, which are subject to social desirability bias and individual interpretation of AI-related concepts. It is also important to emphasize that the study examined self-reported perceptions of productivity rather than objectively measured performance indicators, which limits the ability to draw definitive conclusions about actual productivity outcomes. Employees may have overestimated or underestimated their engagement with AI tools, awareness, or perceived usefulness. Multi-source data, such as supervisor evaluations or system usage logs, could provide more objective insights.

This study focused primarily on individual-level perceptions of AI usage, awareness, and usefulness, without considering team-level or organizational-level factors that may influence productivity, such as collaboration dynamics, managerial support, or organizational culture.

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Incorporating these factors in future research would provide a more comprehensive understanding of AI's impact on performance.

And finally, the study did not differentiate between types of AI tools in depth. While general tools like ChatGPT and Copilot were considered, specialized AI applications for specific tasks may produce different effects on productivity. Future research could investigate tool-specific impacts and their interactions with job roles.

Overall, the study emphasizes that the impact of AI on productivity is not uniform but depends on how employees perceive, interpret, and actively apply these technologies. Strategic alignment of AI adoption with reflective employee practices may therefore be crucial for maximizing the benefits of AI in the IT sector.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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ENTREPRENEURIAL MARKETING AND ORGANIZATIONAL PERFORMANCE: INSIGHTS FROM THE MORAVICA DISTRICT IN SERBIA

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ABSTRACT

Entrepreneurial marketing represents a non-traditional, opportunity-driven marketing approach that is particularly relevant for small and medium-sized enterprises (SMEs) operating in dynamic environments. The aim of this study is to examine how the implementation of various aspects of entrepreneurial marketing influences the organizational performance of manufacturing SMEs in the Moravica District of the Republic of Serbia. The study sample consisted of 50 manufacturing SME owners, selected using a simple random sampling method. Data were collected through a structured questionnaire primarily composed of closed-ended questions. The research findings indicate that respondents demonstrate low levels of innovation and proactiveness. In contrast, they exhibit a strong commitment to effectively utilizing available resources and addressing customer needs and expectations. However, this focus is accompanied by a limited willingness to take risks.

Keywords: entrepreneurial marketing, organizational performance, small and medium-sized enterprises, entrepreneurship.

INTRODUCTION

Many firms struggle to compete in today's challenging environment, where markets are often unstable and unpredictable. Small and medium-sized enterprises (SMEs) are important for economic development of any country. They help by mobilizing limited financial resources, encouraging entrepreneurship, and connecting with larger industries (Simić, 2024, Foghani et al. 2017, Etuk et al., 2014). SMEs play a key role in growing the economy, creating jobs, increasing wealth, and reducing poverty (Simić, 2024, Petrunenko, et al. 2021). Because of this, they are a main focus for governments and economic leaders.

The environment in which firms operate has become extremely turbulent, fluctuating on a daily basis. To succeed, businesses need marketers and SMEs to understand the constant economic changes, adjust quickly, and learn to predict future market needs. However, relying solely on traditional marketing theories makes this nearly impossible. Marketers must broaden their focus to include new and diverse areas of marketing. Unlike these approaches, today's environment forces businesses to be more innovative in marketing and management to stay ahead. One way to achieve this is entrepreneurial marketing. Entrepreneurial marketing is especially suitable for SMEs with limited resources that use unstructured, spontaneous, and reactive marketing activities (Sarwoko & Nurfarida, 2021, Shuremo et al. 2021, Franco et al. 2014, Morris et al., 2002, Becherer et al., 2012).

The importance of the manufacturing sector in the economy is well established in the literature, as manufacturing is considered the engine of economic growth (Halkos et al., 2021). In Serbia, although manufacturing accounts for approximately 15% of the total number of companies, it plays a significantly larger economic role by contributing over one-quarter of the total gross

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value added. Moreover, 99% of all firms are micro, small, or medium-sized enterprises - MSMEs (Statistical Office of the Republic of Serbia, 2024). In the region of Western Serbia which includes 8 districts, there are 19,193 registered companies, of which 4,525 are manufacturing enterprises, and 98% of these belong to the group of MSMEs (Statistical Office of the Republic of Serbia, 2024).

Performance of SMEs is a key determinant of business success, and reflects the results a company achieves over time through the use of its resources, knowledge, and skills (Sarwoko and Nurfarida, 2021). In today's competitive environment, regular performance monitoring is essential for ensuring sustainability and achieving strategic goals. Performance can be measured using financial indicators (such as profit, return on investment, growth, and market value) and non-financial indicators (such as employee satisfaction, service quality, customer satisfaction, and social impact) (Hanaysha & Al-Shaikh, 2022, Ouragini & Lakhal 2024).

This paper aims to explore the impact of entrepreneurial marketing on the performance of manufacturing SMEs in the Moravica District, which is part of the Western Serbia region and includes four municipalities: Čačak, Gornji Milanovac, Lučani, and Ivanjica.

The paper is organized as follows. The first part is dedicated to the literature review, focusing on entrepreneurial marketing and its dimensions. This section concludes with a summary of previous research findings on the impact of entrepreneurial marketing on firm performance and the formulation of research hypotheses. The following section presents the methodology and the methods used for data analysis. Results and a brief discussion are then provided. Finally, the paper concludes with implications, research limitations, and suggestions for future research directions.

LITERATURE REVIEW

Entrepreneurial marketing

Entrepreneurial marketing is a marketing approach that combines key elements of entrepreneurship and marketing (Al-Shaikh & Hanaysha, 2023, Franco et al. 2014,). It is especially suitable for SMEs and startups that operate with limited resources in dynamic and uncertain environments (Yadav & Bansal, 2021). Entrepreneurial marketing helps businesses act in an entrepreneurial way while using marketing tools and processes (Al-Shaikh & Hanaysha, 2023, Sadiku-Dushi et al. 2019, Becherer et al., 2012). This approach focuses on innovation, risk-taking, and flexibility. It allows companies to find new business opportunities and connect with customers more effectively (Morris et al., 2002; Becherer et al., 2012). The combination of entrepreneurial and marketing principles helps firms develop unique value propositions and stand out in competitive markets (Sadiku-Dushi et al. 2019).

Entrepreneurial marketing includes actively searching for opportunities and using them to grow the business and deliver value to customers (Morris et al., 2002, Becherer et al., 2012). It relies on creativity, sales orientation, market involvement, networking, and adaptability (Al-Shaikh & Hanaysha, 2023, Sarwoko & Nurfarida, 2021, Sadiku-Dushi et al., 2019). Entrepreneurial marketing goes beyond just selling and distributing products. It also includes collecting and using different resources, to support business growth (Becherer et al., 2012). It brings an innovative and creative way to deliver products, services, and ideas to markets or segments that were previously unexplored (Al-Shaikh & Hanaysha, 2023, Sarwoko & Nurfarida, 2021).

Dimensions of entrepreneurial marketing

Morris et al. (2002) identified seven key dimensions of entrepreneurial marketing that have been widely accepted by other scholars. These dimensions are: proactiveness, calculated risk-taking, innovativeness, opportunity focus, resource leveraging, customer intensity, and value creation. These dimensions set entrepreneurial marketing apart from traditional marketing. The first five dimensions represent aspects of entrepreneurial orientation, while the last two relate to marketing orientation (Sarwoko & Nurfarida, 2021, Sadiku-Dushi et al. 2019, Becherer et al., 2012, Hacıoglu et al. 2012).

A proactive approach is characterized by taking initiative, responding quickly to market changes, launching products before the competition, identifying hidden customer needs, and

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gathering relevant information that can support better decision-making and achieving a competitive advantage (Al-Shaikh & Hanaysha, 2023, Hanaysha & Al-Shaikh, 2022, Hacıoglu et al. 2012).

Opportunity focus is defined as the ability to identify opportunities for creating value within a dynamic market environment. This capability is considered essential for the success of SMEs, as early recognition of unmet needs enables them to apply innovative strategies and enter the market ahead of their competitors. (Sarwoko & Nurfarida, 2021, Shuremo et al. 2021, Morris et al., 2002, Becherer et al., 2012).

Risk-Taking involves the willingness to invest resources despite uncertain outcomes. Entrepreneurial firms take calculated and rational risks, understanding that innovation carries unpredictability. To manage this, they often form strategic alliances that allow them to share both risk and responsibility (Hanaysha & Al-Shaikh, 2022, Becherer et al., 2012).

Innovation is at the core of entrepreneurial marketing, enabling firms to introduce new products, services, or processes (Becherer et al., 2012). Whether creating entirely new markets or developing existing ones, innovative SMEs use experimentation and informal insights to differentiate themselves even when operating with limited resources (Al-Shaikh & Hanaysha, 2023, Hacıoglu et al. 2012, Morris et al., 2002).

Customer intensity refers to placing the customer at the center of entrepreneurial marketing activities, using innovative methods to understand, meet, and surpass their needs and expectations. Still, concentrating too much on current expectations can slow down the pursuit of radical new ideas and long-term growth (Sadiku-Dushi et al. 2019, Morris et al., 2002).

Resource leveraging highlights the creative use of limited financial, human, or material resources. Entrepreneurs compensate for resource constraints by forming partnerships, applying low-cost tactics such as guerrilla or niche marketing, and gradually scaling their efforts to maximize impact (Becherer et al., 2012, Morris et al., 2002).

Value creation represents the ultimate goal of entrepreneurial marketing. By identifying unaddressed customer needs and combining resources in unique ways, firms generate superior value (either by increasing benefits or reducing costs) which helps them build stronger relationships and achieve competitive advantage (Al-Shaikh & Hanaysha, 2023, Morris et al., 2002).

Alqahtani & Uslay (2020) expanded the main concept by adding an eighth dimension - networking. They replaced "customer intensity" with "inclusive attention" to show a more balanced focus on all stakeholders, not just customers. They also point out that value and opportunities are created through collaboration with consumers and other stakeholders, not only inside the organization. A new view on risk is also introduced. Entrepreneurs and marketers are seen as taking acceptable risks, meaning they risk only what they can afford to lose. Entrepreneurial marketing is described as a way of thinking which, when supported and promoted by top management, can grow into an organizational culture and become the basis for a competitive advantage that is hard to imitate.

Hypotheses development

Numerous studies have examined how entrepreneurial marketing affects SMEs in various contexts. Most of this research originates from developed countries, with limited studies conducted in developing regions and few comparative analyses between regions. Moreover, quantitative methods dominate, with performance and customer orientation appearing as the most frequently investigated topics (Yadav & Bansal, 2021).

Foundational studies of Hacıoglu (2012), Becherer et al. (2012), and Franco et al. (2014) identified a positive relationship between specific entrepreneurial marketing dimensions and firm performance. These studies have been widely used as a conceptual and methodological basis for later studies.

In the context of developing countries, Sadiku-Dushi et al. (2019) examined the influence of entrepreneurial marketing dimensions on the performance of SMEs in Kosovo and found that opportunity orientation, resource leveraging, and value creation had a positive effect on SME performance.

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Similarly, Alqahtani & Uslay (2020) found that entrepreneurial marketing helps companies adapt and survive in unstable and turbulent environments. They found that entrepreneurial marketing has a positive impact on organizational performance, especially in conditions of high market and technological turbulence, intense competition, and strong supplier power. Their results also revealed that the effectiveness of EM depends on firm size: small and large firms benefit the most, while medium-sized firms benefit less. They also highlighted that larger and more diverse networks increase the positive impact of entrepreneurial marketing on performance.

Sarwoko and Nurfarida (2021) explored the importance of entrepreneurial marketing on the business performance of SMEs in Indonesia. They also examined how entrepreneurs' personality traits influence the use of entrepreneurial marketing. The results showed that entrepreneurial marketing has a positive effect on business performance. Traits such as extraversion, conscientiousness, and agreeableness support the use of entrepreneurial marketing, while extraversion, conscientiousness, and openness to experience directly contribute to better business outcomes.

In the Ethiopian context, Shuremo et al. (2021) found that innovation orientation and customer focus have a positive influence on performance, while risk-taking orientation negatively affects business outcomes.

Nwankwo and Kanyangale (2022) investigated the impact of entrepreneurial marketing on the survival of small and medium manufacturing enterprises in Nigeria. Their findings indicate that entrepreneurial marketing has a direct and significant positive effect on SME survival, with dimensions such as proactiveness, calculated risk-taking, resource leveraging, customer intensity, value creation, market sensing, and teamwork contributing positively, while innovativeness showed a significant but negative effect on survival.

Ouragini & Lakhal (2024) conducted a study that included companies of various sizes and from different sectors, and found that different dimensions of entrepreneurial marketing positively influence firm performance. All dimensions proved to be significant, with innovation and customer orientation standing out as particularly important, while calculated risk-taking had a moderate impact. Hanaysha & Al-Shaikh (2022) obtained similar results while investigating the same topic on SMEs in Saudi Arabia. Their results showed that customer orientation and value creation positively affect firm performance, innovation and resource leveraging, while risk-taking showed no statistically significant effect. Proactiveness and opportunity orientation were also found to be significant contributors to firm performance.

In Serbia, researchers Vukajlović & Stamatović (2013) have examined entrepreneurial marketing and found that companies generally engage in entrepreneurial and marketing activities on a regular basis. However, these efforts are often constrained by limited resources and insufficient attention to sustainability, with no significant differences observed across company sizes or industries. Okanović (2016) examined market orientation in the development of technology-based entrepreneurial ventures by linking market orientation and entrepreneurial orientation. Theoretical analysis showed that these concepts share common elements with entrepreneurial marketing. Stošić Pantić (2017) examined the strategic orientation of Serbian entrepreneurs and found that, overall, they tend to adopt an entrepreneurial approach to growth, innovation, and marketing.

In Serbia, entrepreneurial marketing has been studied in various contexts (e.g. Vukajlović & Stamatović (2013), Okanović (2016), Stošić Pantić (2017)) but none of the researchers have focused on its specific dimensions, which represents the main contribution of this study.

Research conducted so far clearly shows a strong connection between entrepreneurial marketing and SME performance, with entrepreneurial marketing recognized as one of the key drivers of success. Based on previous research findings and theoretical background, the following hypotheses were formulated:

- H1: Proactiveness has a positive impact on overall SMEs performance.
- H2: Calculated risk taking has a positive impact on overall SMEs performance.
- H3: Opportunity focus has a positive impact on overall SMEs performance.
- H4: Innovativeness has a positive impact on overall SMEs performance.

- H5: Customer intensity has a positive impact on overall SMEs performance.
- H6: Resource leveraging has a positive impact on overall SMEs performance.
- H7: Value creation has a positive impact on overall SMEs performance.

METHODOLOGY

The main goal of this study was to examine influence of entrepreneurial marketing (EM) dimensions on the organizational performance (OP) of manufacturing small and medium-sized enterprises (SMEs) in the Moravica District of Serbia. For the purposes of the study, an adapted questionnaire was developed, consisting of 65 questions divided into three main sections. The first section was designed to collect basic information about the enterprise, including its industry, year of establishment, legal structure, and number of employees. The second section focused on seven dimensions of entrepreneurial marketing, which were defined based on previous research, and for this purpose, the scale developed by Becherer et al. (2012) was selected as the most appropriate tool. This scale captures seven dimensions of entrepreneurial marketing (proactiveness - P, innovation - I, opportunity focus - OF, calculated risk-taking - RT, customer intensity - CI, value creation - VC, and resource leveraging - RL) which are treated as independent variables. The third section aimed to evaluate the overall performance of the enterprise. This part is measured by 18 items, adapted from Sadiku-Dushi et al. (2019). Both the second and third sections were assessed using a 7-point Likert scale.

The questionnaire was distributed in electronic format and sent via email to the owners of micro and small enterprises operating in the Moravica District. The data were collected from 50 manufacturing enterprises. The data collection process was carried out between January and April 2025. Preliminary statistical analyses were conducted using SPSS software and included descriptive statistics, reliability testing (Cronbach's alpha), and regression analysis.

The sample consisted of 60% of enterprises from Čačak, 15% from Gornji Milanovac, 11% from Lučani, and 7% from Ivanjica. The largest number of enterprises in the sample (38%) have been operating for nearly three decades. A significant share (37%) are young enterprises that have been on the market for less than 10 years, 14% have been in business for up to 20 years, while the remaining companies have been operating for over 40 years. The sample included an almost equal number of different legal business forms, comprising 54% sole proprietorships and 46% limited liability companies or other business entities. The largest share, 48%, belonged to the category of micro-enterprises (up to 10 employees), 46% were small enterprises (10 to 50 employees), while only 6% were medium-sized enterprises (50 to 250 employees).

RESULTS AND DISCUSSION

Reliability analysis for all variables was conducted using Cronbach's alpha coefficient. Good reliability and internal consistency were confirmed for the most variables. Scales such as P, OF, and RL show marginal (0.627, 0.648 and 0.698 respectively), yet still acceptable values. According to the literature (e.g. Sadiku-Dushi et al., 2019, Becherer et al., 2012), Cronbach's alpha values of 0.6 or above can be considered acceptable in exploratory research. For this reason, all scales were retained for further analysis. The results of the reliability analysis are presented in Table 1.

The means across variables range from 4.01 (RT) to 5.74 (CI), reflecting moderate to high average responses. The greatest variability was observed in opportunity focus ($SD_{OF} = 1.19$), suggesting more diverse opinions among respondents, while customer intensity showed the most consistent answers ($SD_{CI} = 0.74$).

Normality of the distributions was evaluated based on skewness and kurtosis values, as well as the Shapiro-Wilk test, and the results are presented in Table 1. Most variables show slight skewness and moderate kurtosis, indicating relatively stable distributions with minor deviations from normality. However, the variable opportunity focus shows a more pronounced negative skewness (-1.182), suggesting a significant deviation from a symmetric distribution. This was confirmed by the Shapiro-Wilk test, where all p-values were below the 0.05 threshold. Therefore, the assumption of normality was not met for any variable, and non-parametric statistical methods were applied in subsequent analyses (Pallant, 2011).

Table 1. Results of reliability and descriptive analysis and normality tests.

Variable	Cronbach's alpha	Mean	Std. deviation	Skewness	Kurtosis	Shapiro-Wilk (N=50)	
						W	p-value
Proactiveness (P)	0.627	5.1433	0.830	0.424	0.344	0.943	0.036
Innovativeness (I)	0.836	5.3200	1.067	- 0.076	-0.906	0.941	0.031
Opportunity focus (OF)	0.648	5.0083	1.188	- 1.182	0.836	0.920	0.006
Risk taking (RT)	0.873	4.0139	1.023	0.688	-0.466	0.863	0.000
Customer intensity (CI)	0.833	5.7431	0.739	0.198	- 0.567	0.923	0.008
Resource leveraging (RL)	0.698	5.4196	0.896	- 0.680	0.799	0.934	0.018
Value creation (VC)	0.824	5.4257	0.993	- 0.508	- 0.237	0.938	0.025
Performance (OP)	0.754	5.2000	1.003	- 0.495	- 0.555	0.881	0.000

Table 2 presents the Spearman's rho correlation coefficients between the analyzed variables. Significant positive correlations were found between most constructs, especially between VC and P ($\rho = 0.856$, $p < 0.01$), as well as between I and VC ($\rho = 0.762$, $p < 0.01$). Only variable RT showed no significant correlations with other variables.

Compared to the Ouragini & Lakhal (2024) study our findings also confirm strong positive relationships between I, VC, and OP. This is consistent with their results showing high correlations between I and OF ($r=0.738$) and CI ($r=0.546$). However, unlike their study, which reported strong links between P and both RT ($r=0.628$) and RL ($r=0.532$), our analysis did not find these correlations to be statistically significant. These differences may be attributed to variations in sample size (328 versus 50 respondents), firm size (including large enterprises in their case), differences in correlation methods (Pearson vs. Spearman) and cultural context.

Our results indicate that the strongest positive correlation with OP was found for the variable VC ($\rho = 0.856$), followed by P ($\rho = 0.613$) and I ($\rho = 0.576$). These findings are partly consistent with previous research (Sadiku-Dushi et al., 2019), where the same dimensions also showed the highest correlations, although with slightly lower values. However, in the same study a moderate positive relationship was found between RT and OP, while in our results this relationship was not statistically significant.

Table 2. Correlation analysis.

Variable	P	I	OF	RT	CI	RL	VC
P	1						
I	0.584**	1					
OF	0.498**	0.589**	1				
RT	- 0.009	- 0.019	0.253	1			
CI	0.430**	0.623**	0.614**	0.129	1		
RL	0.215	0.120	0.395**	0.639**	0.055	1	
VC	0.696**	0.762**	0.497**	-0.116	0.659**	-0.002	1
OP	0.613**	0.576**	0.481**	-0.083	0.447**	0.106	0.856**

** $p < 0.01$

The hypothesis testing in this study is conducted by running a regression analysis. Table 3 shows the result of the multiple linear regression.

Table 3. Multiple linear regression analysis.

EM Dimension Entered	B	Standard Error	Beta	t	Sign. (p)	Collinearity Statistics	
						Tolerance	VIF
Constant	1.131	0.814	-	1.390	0.173		
P	-0.203	0.117	-0.199	-1.730	0.093	0.511	1.959
I	-0.282	0.156	-0.244	-1.805	0.079	0.376	2.661
OF	0.278	0.111	0.339	2.508	0.016*	0.379	2.641
RT	0.056	0.085	0.082	0.660	0.514	0.438	2.286
CI	-0.145	0.112	-0.146	-1.1293	0.204	0.533	1.877
RL	-0.034	0.118	-0.037	-0.288	0.776	0.416	2.402
VC	0.787	0.153	1.076	5.132	0.000**	0.355	2.820

Dependent Variable: Organizational performance, $R^2 = 0.769$; $F = 16.284$; $Sig = 0.000$, * $p < 0.05$, ** $p < 0.01$
N=50

The model was statistically significant and explained 76.9% of the variance in organizational performance ($R^2 = 0.769$, Adjusted $R^2 = 0.721$, $p < 0.001$), indicating a strong relationship between the analyzed dimensions and organizational performance. Among the examined variables, VC ($\beta = 1.076$, $p < 0.001$) and OF ($\beta = 0.339$, $p = 0.016$) emerged as statistically significant positive predictors of performance. The other variables (P, I, RT, CI, and RL) did not show a significant individual contribution in this model. Since all tolerance values are above 0.2 and VIF values are below 5, multicollinearity is not a problem in this analysis. Although the variable RT did not exhibit a statistically significant correlation with OP ($\rho = -0.083$, $p = 0.561$), it showed a positive but non-significant standardized coefficient in the regression model ($\beta = 0.082$, $p = 0.514$). This suggests that RT, while not a strong factor on its own, may still play a minor supportive role when considered in combination with other entrepreneurial marketing dimensions.

Our findings confirmed the H3 and H7 and suggest that SMEs benefit significantly from a strong opportunity focus and value creation orientation. These two entrepreneurial dimensions showed a positive and statistically significant effect on organizational performance, which is consistent with the results of previous studies (e.g., Becherer et al., 2012; Sadiku-Dushi et al., 2019, Sarwoko & Nurfarida, 2021, Nwankwo & Kanyangale, 2022, Hanaysha & Al-Shaikh, 2022, Ouragini & Lakhal, 2024), where opportunity recognition and value creation were also found to have a positive influence on firm performance.

The other examined dimensions did not show significant predictive power in this model, which contrasts with several earlier studies in which customer intensity and resource leveraging demonstrated a positive effect on organizational performance (e.g., Ouragini & Lakhal, 2024, Sarwoko & Nurfarida, 2021). Thus, H1, H2, H4, H5, and H6 are rejected.

Moreover, some prior research (e.g., Sadiku-Dushi et al., 2019, Shuremo et al., 2021) identified even negative relationships between proactiveness and risk-taking and SME performance, further highlighting the contextual sensitivity of entrepreneurial marketing outcomes.

CONCLUSIONS

The conducted research aimed to examine how the dimensions of entrepreneurial marketing influence the organizational performance of small and medium-sized manufacturing enterprises in Serbia, with a focus on the Moravica District.

Our results showed that only two (opportunity focus and value creation) of the seven dimensions of entrepreneurial marketing have a statistically significant impact on organizational performance in Serbia. Since research on entrepreneurial marketing dimensions has not been

Rendulić Davidović, G. et al. (2025). Entrepreneurial marketing and organizational performance: insights from the Moravica district in Serbia. *STED Conference 14*(2), 89-97.

conducted in this form in Serbia, our findings may act as a reference point for further studies and comparative research in other regions.

This study has some limitations that should be considered. The sample was relatively small (N=50) and included a specific sector - manufacturing SMEs from a single district, which may limit the generalizability of the findings. Additionally, the questionnaire used could be further adapted to the specific business environment and cultural context of Serbia, in order to increase the relevance and accuracy of measurement. Although these findings offer valuable insights, it is important to note that they are based on a preliminary study, which is planned to be extended to other regions of Serbia in future research stages.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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MOGUĆNOSTI PODSTICANJA INTERNIH PREDUZETNIČKIH INICIJATIVA KOD ZAPOSLENIH U PROIZVODNIM FIRMAMA - STUDIJA SLUČAJA KOMPANIJA VENDOM

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SAŽETAK

Interno preduzetništvo predstavlja proces koji se zasniva na kreiranju i implementaciji inovativnih ideja unutar postojećih organizacija, sa ciljem unaprijeđenja poslovne strategije, poboljšanja operativne efikasnosti i ostvarivanja dugoročnih konkurentskih prednosti. Kreativna i inovativna rješenja razvijena kroz koncept internog preduzetništva rezultiraju stvaranjem novih proizvoda usluga ili dodatnih vrijednosti koje organizacija može ponuditi tržištu, odnosno drugim kompanijama, čime se jača njena konkurentska pozicija. Inovativnost zaposlenih dobrim dijelom se javlja kao rezultat osobenosti svakog pojedinca, što bi trebalo da predstavlja značajan potencijal svake kompanije. Predmet istraživanja ovog rada predstavljaju preduzetničke inicijative i mogućnosti njihovog podsticaja u preduzećima. U tu svrhu u radu je prezentovana studija slučaja kompanije iz oblasti metalske industrije gde su prikazani primjeri internih preduzetničkih inicijativa. Bez obzira na određene rizike i izazove koji mogu pratiti pojedine preduzetničke inicijative zaposlenih, nameće se zaključak da kompanije mogu imati više benefita i da i budućnosti savremenog poslovanja mora podržati inovativnost zaposlenih kroz podršku i stimulaciju njihovih ideja.

Ključne riječi: interno preduzetništvo, proizvodno preduzeće, ključni faktori, inovacija, menadžment.

UVOD

Konkurentsko rivalstvo moderne industrije intenziviralo je potrebu kompanija da postanu preduzetnije i inovativnije kako bi opstale i napredovale na tržištu. Naime, u vrijeme ubrzane globalizacije tržišta, praksa je pokazala da preduzeća koja žele da budu konkurenta na tržištu, moraju biti sposobna da se brzo prilagode, transformišu ili mijenjaju kako bi ispunila očekivanja potrošača. Da bi unaprijedile svoju proizvodnju i ostvarile, ili čak nadmašile, postavljene ciljeve, kompanije moraju poboljšati svoju sposobnost inoviranja, što podrazumijeva efikasno korišćenje kreativne snage svojih zaposlenih (Lee & Pati, 2017).

Cilj svake ozbiljne kompanije je postizanje konkurentске prednosti. Najpouzdaniji izvor sticanja dugoročne konkurentске prednosti predstavlja sposobnost učenja, kako zaposlenih orijentisanih ka razvoju preduzeća, tako i kompanije kao cjeline. Učenje podrazumijeva napuštanje starih u korist novih poslovnih metoda, kao i primjenjivanje novostečenih znanja i vještina u svakodnevним poslovnim aktivnostima. Sposobnost transformacije iz tradicionalnih načina poslovanja i prihvatanja novih, predstavlja veoma važnu kariku u kontekstu uvođenja inovacija, s obzirom da korištene pretpostavke i organizacione rutine vremenom mogu zastariti i postati prevaziđene, što dalje otežava odvijanje preduzetničkih procesa u organizaciji. Upravo iz tog razloga, kontinuirana edukacija igra ključnu ulogu jer doprinosi povećanju kapaciteta organizacije da efektivnije koristi dostupne resurse, podstičući sistematsko inoviranje poslovnih procesa i unaprijeđenje načina kreiranje nove vrijednosti (Erić Nielsen, 2015).

Đukanović, S. i sar. (2025). Mogućnosti podsticajnih internih preduzetničkih inicijativa kod zaposlenih u proizvodnim firmama – studija slučaja kompanija Vendom. *STED Conference 14*(2), 99-110.

U savremenim uslovima poslovanja, kontinuirano inoviranje predstavlja ključni preduslov ostvarivanja održive konkurentske prednosti, ali i jedan od glavnih pokretača rasta i razvoja nacionalne ekonomije. Stepenn inovativnosti unutar organizacije u velikoj mjeri zavisi od spremnosti zaposlenih da aktiviraju i primjene svoje kreativne potencijale u funkciji unapređenja poslovanja i daljeg razvoja preduzeća. Iako na inovativno ponašanje zaposlenih utiče čitav niz objektivnih i subjektivnih faktora, posebno se izdvajaju oni koji potiču iz samog preduzeća - poput organizacione kulture, sistema nagrađivanja, stilova rukovođenja i mogućnosti za profesionalni razvoj (Erić, Nikolić, & Dukanac, 2023, str. 87).

Cilj ovog rada je da dodatno približi sve prednosti internog preduzetništva. Kao primjer je poslužila studija slučaja u kompaniji „Vendom“ gdje su prikazana tri primjera internih inicijativa zaposlenih (optimizacija procesa plaćanja, automatizovano robotsko zavarivanje i unaprijeđenje informacionog sistema preduzeća modifikacijom) koja su donijela direktne višestruke benefite kompaniji.

Struktura rada je takva da je u prvom dijelu rada akcenat stavljen na teorijske osnove internog preduzetništva, njegov značaj, karakteristike i načine primjene. Nakon toga, analizirani su faktori koji utiču na razvoj i realizaciju interne preduzetničke ideje. Na kraju su navedene prednosti i nedostaci internog preduzetništva. U drugom dijelu rada predložena je studija slučaja preduzeća Vendom d.o.o, koje posluje u oblasti metalne industrije, i ima značajna iskustva vezana za interno preduzetništvo. S tim u vezi, u navedenom preduzeću, prezentovani su konkretni primjeri internog preduzetništva kao što su: optimizacija procesa plaćanja, robotizacija procesa proizvodnje i unaprijeđenje informacionog sistema). Na kraju rada data su zaključna razmatranja i predložena je korištena literatura.

INTERNO PREDUZETNIŠTVO

Savremena teorija o preduzetništvu ne nudi jedinstvenu i opšteprihvaćenu definiciju ovog pojma, te broj definicija proporcionalno raste sa brojem autora koji se bave ovom temom. U ovom radu osvrt je dat na jednu od često korišćenih definicija, prema kojoj se preduzetništvo definiše kao proces koji se sastoji od kreiranja nečeg novog, koji zahtijeva vrijeme, i značajan lični angažman i ulaganje, uz preuzimanje različitih vrsta rizika - psiholoških, finansijskih i drugih - s ciljem postizanja materijalne i nematerijalne satisfakcije (Hisrich, 1986).

Suština preduzetništva ogleda se u aktivnosti u čijoj je srži inovacija, odnosno težnja i napor ka stvaranju svrsishodnih i usmjerenih promjena, bilo osnivanjem novih preduzeća ili implementacijom inovativnih ideja unutar već postojećih organizacija. U zavisnosti od konteksta u kojima se preduzetnička aktivnost realizuje - da li kroz formiranje novih malih preduzeća od strane pojedinca ili pod okriljem već etabliranih kompanija, razlikuje se eksterno ili interno preduzetništvo (Aničić, 2019). Eksterno orijentisano preduzetništvo može se definisati kao proces u kojem pojedinac ili tim, kombinovanjem resursa iz šireg okruženja sa sopstvenim jedinstvenim resursima, stvara novu kombinaciju koja je u potpunosti nezavisna od postojećih organizacionih struktura (Aničić, 2019).

Pojam internog preduzetništva

Termin interno preduzetništvo, odnosno interni preduzetnik (engl. *intrapreneuer*) prvi put se pojavio 1978. godine u knjizi „Intrakorporativno preduzetništvo“ (engl. *Intra-Corporate Entrepreneurship*), Džiforda Pinčota III i Elizabet S. Pinčot (Gifford Pinchot III, Elizabeth S. Pinchot), koji su pod tim terminom smatrali ličnost koja koristi inovacije da bi kreirala novi ili poboljšala već postojeći proizvod ili proces (Cadaru & Badulescu, 2015). Pinčot (1985) će nekoliko godina kasnije dopuniti svoju prvobitnu definiciju smatrajući interne preduzetnike sanjarima koji rade, odnosno onima koji preuzimaju odgovornost za stvaranje inovacije bilo koje vrste unutar organizacije (Cadaru & Badulescu, 2015). Godine 1992, u Američkom rječniku (engl. *The American Heritage Dictionary of the English Language – AHD*) prvi put je data definicija riječi „*intrapreneur*“, koja se već uveliko koristila u naučnim krugovima, podrazumijevajući pod tom riječju ličnost unutar velike kompanije koja preuzima direktnu odgovornost za pretvaranje ideje u

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profitabilan gotov proizvod, preuzimajući odgovornost, kako za inoviranje, tako i za rizik (Beatie, 1992).

Uopšteno, pod internim preduzetništvom podrazumijeva se proces koji se temelji na kreiranju inovativnih ideja unutar postojećih organizacija, sa ciljem unaprijeđenja poslovne strategije i ostvarivanja dugoročnih uspjeha (Alphabet Group, 2025). Rješenja nastala kroz koncept internog preduzetništva, često rezultiraju razvojem novih proizvoda, usluga, ili novih vrijednosti koje organizacija može plasirati na tržište, odnosno ponuditi drugim kompanijama, čime se dodatno jača njena konkurentska pozicija. Interno preduzetništvo, u svojoj suštini, podrazumijeva inkorporaciju novih inovativnih poslovnih ideja unutar već postojećih organizacija/preduzeća kako bi se podigao kvalitet ili poboljšala efikasnost poslovanja, a samim tim i unaprijedila konkurentska pozicija na tržištu, to jest, “uvođenje i implementaciju značajne inovacije ili inovacija za preduzeće od strane jednog ili više zaposlenih koji su zaposleni u preduzeću” (Carrier, 1996, str. 6).

Inovativnost zaposlenih dobrim dijelom se javlja kao rezultat osobenosti svakog pojedinca, što bi trebalo da predstavlja značajan potencijal svake kompanije. Inovacija predstavlja specifično oruđe preduzetnika pomoću kojeg preduzetnici koriste modifikaciju kao mogućnost za izvršenje različitih proizvodnih ili uslužnih aktivnosti (Drucker, 1985). Prema Drakeru (1985), preduzetnici treba na svrsishodan način da istražuju moguće izvore inovacija, promjene i njihove simptome, koji označavaju mogućnosti za ostvarenje uspješnih inovacija. Nadalje, Marić, Leković i Petković (2010) pod internim preduzetništvom posmatraju posebnu vrstu preduzetništva koje karakterišu aktivnosti koje se odnose na: “opažanje mogućnosti, generisanje ideja, kreiranje nečeg novog (proizvoda, metoda rada, delova poslovnih procesa, novog tržišta, itd.), nove kombinacije resursa koje uz podršku menadžmenta, dostupnost resursa i uz adekvatno planiranje i organizovanje svih pomenutih aktivnosti postaju realnost za značajnim doprinosom u organizaciji”. Neki drugi autori, kao npr. Bušra i Ahsan (2011, str. 3), posmatrali su interno preduzetništvo kao „način podsticanja inovacija unutar kompanije koristeći kreativni talenat radne snage i pružajući im potrebna sredstva i slobodu djelovanja unutar organizacije“. Njihov koncept ima korijene u uvjerenju da je uspješna inkorporacija brzih i efikasnih inovacija glavna osnova trajne konkurentске prednosti u savremenom dobu, ostavljajući organizacijama samo dvije mogućnosti: da kvalitetno inoviraju ili da prestanu da postoje.

Osnovne karakteristike internog preduzetništva

Interno preduzetništvo pretpostavlja uobličavanje takvog podsticajnog okruženja u kojem bi svi zaposleni mogli slobodno plasirati svoje ideje i raditi na razvoju proizvoda. Takav pristup zaposlenima daje veći stepen kontrole nad onim čime se bave, što svakako predstavlja određeni tip motivacije i povećava angažovanost radnika (Matias, Ambrocio, Balinong, & Yacap, 2024). Uzimajući u obzir navedeno, jasno je da interno preduzetništvo može povećati osjećaj pripadnosti i povezanosti zaposlenih sa preduzećem, što obično dovodi i do povećane angažovanosti, jer se zaposleni osjećaju kao bitan dio proizvodnog procesa.

Sve interne preduzetničke aktivnosti usmjerene su na implementaciju novih rješenja sa ciljem transformacije prethodno postojećih proizvoda ili usluga. Da bi se postigli značajni efekti koji proizlaze iz implementiranih inovacija koje povećavaju konkurentsku poziciju kompanije, moraju se u obzir uzeti determinante koje utiču na interno preduzetništvo, s obzirom da ono ne predstavlja jednokratnu i slučajno izabranu pojedinačnu akciju, već veoma složen proces. Kao rezultat ovog procesa, implementira se projekat (proizvod/usluga) koji poprima mnoštvo različitih oblika. S obzirom da preduzetnički proces karakteriše donošenje veoma značajnih odluka, rezultati preduzetničkih aktivnosti su zavisni od kvaliteta i efikasnosti donošenja tih odluka, te od menadžmenta, koji treba da omogućiti potrebne resurse za vođenje projekta, njegovo funkcionisanje i efikasnost. Iako se interni preduzetnički proces sastoji od nekoliko blisko povezanih faza (inovativne ideje, motivacije, sredstava za implementaciju, implementacije i analiza rizika), sve preduzetničke aktivnosti: prikupljanja resursa, formalizacije projekta i implementacije projekta trebaju biti u skladu s logikom efikasnog izvođenja i ne moraju se izvoditi uvijek istim i zacrtanim redoslijedom (Gajda, 2015).

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Mogućnost preduzeća da kontinuirano radi na inovacijama proizvoda i usluga, odnosno da stvara inovativan poslovni sistem, predstavlja osnovu njegovog uspjeha. Jasno je da se inovativnost u nekoj proizvodnoj kompaniji ne može postići bez strukturnog menadžerskog okvira za stimulisanje inovacija. Sama mogućnost stimulisanja inovacija zavisi od kvaliteta potencijalnih ideja i rješenja problema koja su ugrađena u proces inovacije. Takav okvir teoretičari obično nazivaju umrežena kreativnost, a ista pretpostavlja mogućnost organizacije da se kontinuirano bavi inoviranjem svojih proizvoda i/ili usluga, pa čak i ukupnog poslovnog sistema radi postizanja uspjeha, povećavanja dobiti i opstanka na tržištu (Brennan & Dooley, 2005).

Određena istraživanja (Gajda, 2015) posebno su naglasila da je snažna organizacijska podrška važna za interno preduzetništvo, uključujući i top menadžment, kako bi se uspješno sprovele kako manje inovacije, tako i radikalne i revolucionarne promjene. Naime, podrška unutar kompanije za bilo koju inovaciju podstiče kreativnost i preuzimanje rizika, omogućavajući internim preduzetnicima da slobodno ulaze u kreiranje određenih poboljšanja, ili novog proizvoda, bez straha od ličnog finansijskog gubitka.

Koristeći svoju kreativnost i nadarenost, interni preduzetnici mogu pokrenuti značajne inovacije i transformisati neka od radnih mjesta. Interni preduzetnici su obično visoko motivisane osobe koje posjeduju specifične vještine, kao i liderske sposobnosti i inovativnu viziju koju drugi u kompaniji mogu podržati. Iako interni preduzetnici mogu imati svoja zaduženja i uobičajene zadatke koji proizilaze iz redovnih poslovnih aktivnosti, kompanija takvim osobama najčešće pruža mogućnost da pored toga imaju vremena i za iskazivanje njihove kreativnosti. To znači da su interni preduzetnici spremni preuzeti određene rizike i, prateći trendove na tržištu, predložiti korake koje kompanija trebati učiniti da bi se inovirala ili da bi se nadmašila konkurenciju.

Postoji više načina primjene internog preduzetništva, koje kvalitetnom primjenom može dovesti do širenja preduzetničkog duha kod zaposlenih, njihove povećane kreativnosti i inovativnosti, a samim tim i stvaranja novih vrijednosti unutar organizacije. Jedan od najvažnijih načina jeste uticaj na razvoj novih proizvoda ili usluga, što bi velike kompanije trebale da iskoriste. Dobar primjer je svjetski poznata kompanija „Google“ koja je veoma rano shvatila prednosti internog preduzetništva uvodeći poslovnu politiku po kojoj svi zaposleni imaju mogućnost da oko 20% svog radnog vremena iskoriste za razvoj ličnih projekata. Ovakav pristup je dao odlične rezultate koji su rezultovali velikim i bitnim projektima. Naime na ovakav ili sličan način su razvijeni neki od najpoznatijih Google servisa, primjera radi, *Gmail*, *Google Maps*, *Google Assistant* (Savoia & Copeland, 2011). Čest način primjene internog preduzetništva je kroz unaprijeđenje procesa i operacija što su primjera radi, uradile poznate kompanije *Dell* i *Amazon*. I dok je *Dell* kroz interno preduzetništvo razvio inovativni proces direktne proizvodnje, dotle je *Amazon*, zahvaljujući internom preduzetništvu, razvio efikasan sistem logistike i distribucije. Na kraju, interno preduzetništvo se takođe može primijeniti i pri razvoju novih poslovnih modela.

Razvoj, realizacija i značaj internog preduzetništva

Mnogi faktori su igrali ulogu u razvoju i širenju koncepta internog preduzetništva. S tim u vezi, Kuratko i Hodžets (2000) pomenuli su neke od njih: veoma brz porast broja postojećih i novih konkurenata; značajno povećanje potrošnje; pojava da inteligentni i inovativni zaposleni napuštaju kompanije u kojima rade obično prelazeći u manje kompanije gdje ih više cijene ili pokreću samostalan biznis; globalizacija promjene koje su povećale međunarodno konkurenciju; brze tehnološke promjene; želja za većom sopstvenom efikasnošću i sl.

Postoji više razloga za podržavanje razvoja internog preduzetništva u kompaniji. Šaper i Voleri (2007) navode neke od najvažnijih: (1) unaprijeđenje i diversifikacija poslovanja; (2) zadržavanje u kompaniji inovativnih, obrazovanih i motivisanih radnika; (3) podizanje stepena iskorišćenosti nedovoljno iskorišćenih resursa na nove načine; (4) rješavanje nepotrebnih aktivnosti ili aktivnosti koje donose samo gubitke.

Određeni autori navode korake koje bi svako preduzeće trebalo da preduzme da bi se kvalitetno pripremilo za razvoj internog preduzetništva (Blanka, 2019). Kao prvo, treba izgraditi kulturu podrške koja podrazumijeva podržavanje inovacije, ali i rizika koji ide sa novinama u poslovanju. Ovo je najlakše postići kroz stvaranje pozitivnog okruženja u kojem zaposleni mogu

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slobodno iznositi i razvijati svoje ideje bez straha od bilo kakvih sankcija. Nakon toga, treba da se predvide i osiguraju resursi potrebni za razvoj internog preduzetništva, što podrazumijeva kako finansijska sredstva, tako i neophodnu tehnologiju potrebnu za realizaciju ideja, inovacija, proizvoda ili projekata. Takođe je neophodno imati i mrežu podrške, koja će, kada bude stvorena, moći da pruži svim zaposlenima stručnost, eventualnu mogućnost edukacije i druge resurse potrebne za razvoj projekata. Na kraju je potrebno osmisliti procese za razvoj, evaluaciju i implementaciju projekata, što između ostalog podrazumijeva procese za prijavljivanje i evaluaciju ideja, odabir projekata, upravljanje projektima i dr. Sve ovo bi trebalo dovesti do toga da preduzeće bude spremno da prihvati promjenu, te da se shodno svakom pojedinačnom projektu prilagođava. Ovo u nekim slučajevima može značiti i odustajanje od novog proizvoda ili projekta, ako se pokaže da isti nije rentabilan.

Svi zaposleni koji su na bilo koji način uključeni u interno preduzetništvo moraju imati hrabrosti, ali i pokretačku snagu da nove i neprovjerene ideje i inovacije implementiraju u praksi. Svi aspekti koji su u vezi sa kombinovanjem resursa na inovativan način uključeni su u inovaciju, od relativno manjih poboljšanja ili inovacija usluga, proizvoda, rutina i procedura, ili organizacionog dizajna do radikalnijih promjena (Saly, 2001). Upravo činjenica da se nešto mora mijenjati ili razvijati, i da to neko mora učiniti, pokreće proces internog preduzetništva. Većina inovacija se ne smatra očiglednim ili neophodnim sve dok se nova ideja ne implementira.

Kada se uđe u proces realizacije nečega novog i još nedovoljno ispitano, obično se u okviru zaposlenih formira projektni tim koji se dugoročno može razviti u interni preduzetnički tim sa kolektivnijim imidžom. Po nekim autorima (Mack, Green, & Vedlitz, 2008) veoma je bitno da se interno preduzetništvo od početka do kraja posmatra kao grupni proces, odnosno kao kolektivna akcija, s obzirom da je manje vjerovatno da će samo jedan zaposleni imati na raspolaganju svu moć i resurse. Čak i u takvim okolnostima unutar internog preduzetničkog tima, mora da postoji jedna osoba koja se smatra vođom tima i čije su nadležnosti veće od drugih članova tima. To znači da većinu timova vodi jedan interni preduzetnik, ali se i svi drugi članovi tima mogu nazvati internim preduzetnicima, sve dok se svaki od njih razumije u cijeli projekat i neprestano radi na pronalaženju najboljih načina da se on ostvari. Ono što je takođe bitno naglasiti jeste da interni preduzetnički tim, kada ima inovativnu ideju u koju vjeruje, mora pronaći ljude u organizaciji koji će podržati i zastupati njihovu ideju, iz razloga što bilo kakva inovacija tokom realizacije stvara direktne troškove te novac mora biti dostupan da bi se omogućio nastavak započetog procesa. U slučaju da postoje poteškoće, pogotovo novčane prirode, može se desiti da se privremeno zaustavi realizacija inovativnog projekta ili čak prekine sa njim. Naime, ako interni preduzetnički tim nema raspoloživih sredstava, neće biti u stanju da implementira sve potrebne mjere. Ovdje treba naglasiti da se preduzeća susreću sa mnogo više problema u pronalaženju sredstava za finansiranje istraživačko-razvojnih aktivnosti nego, primjera radi, za ulaganja u osnovna sredstva (Mateut, 2018). Ovo je logično iz razloga visokog stepena nesigurnosti inovacionih projekata zbog obično dugog perioda povraćaja sredstava i nepredvidivosti prihvatanja inovacije na tržištu. Upravo zbog visoke nepredvidivosti inovacija, institucije koje daju zajam, najčešće banke, radije finansiraju niskorizične projekte, odnosno projekte za koje mogu zahtijevati i dobiti garancije i kolateral (Erić, Nikolić, & Dukanac, 2023). Pritisak sa tržišta primorava kompanije da vode računa o adekvatnom izvoru i iznosu finansiranja za inovacione projekte.

Podrška inovativnom timu može imati mnogo različitih oblika, npr. podrška menadžera višeg nivoa, diskrecija u radu (sloboda odlučivanja kako da se posao obavlja), jasno definisani sistemi nagrađivanja/stimulacije, dostupnost resursa i sistema upravljanja (Diefenbach, 2011). Svakako da je najvažnija jaka organizaciona podrška, uključujući podršku najvišeg menadžmenta, jer je interno preduzetništvo sekundarna djelatnost organizacije. S obzirom da se radi o sekundarnoj djelatnosti kompanije sistem upravljanja treba osigurati kontinuirane informacije o inovativnim projektima. Ovo zahtijeva uspostavljanje administrativnih veza kako bi najvišem rukovodstvu pravovremeno stizali izvještaji o načinima na koji se realizuju strateški ciljevi, kako se upravlja raspodjelom resursa i kako se određuju proizvodni odnosi.

O značaju internog preduzetništva u moderno vrijeme najbolje govori zaključak Američke multinacionalne analitičke i savjetodavne kompanije Galup (engl. *Gallup, Inc.*) sa sjedištem u

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Vašingtonu, koja je po osnovu istraživanja u jednoj svojoj studiji (*State of the Global Workplace* 2013) došla do zaključka da su kompanije s visoko angažovanim i inovativnim zaposlenicima do 21% profitabilnije u odnosu na kompanije koje u svom poslovanju ne koriste inovativnost zaposlenih (Celestin, Vasuki, Sujathu, & Dinesh Kamar, 2024).

S tim u vezi, u adekvatnoj implementaciji internog preduzetništva neophodno je kvalitetno postaviti sistem nagrađivanja, stimulacija ili drugih vidova podsticaja za zaposlene koji su angažovani, pogotovo za one čije inovacije mogu da donesu značajan profit ili neki drugi vid benefita za kompaniju. Na taj način će se i svi drugi zaposleni više motivisati da u nekom budućem vremenu plasiraju, razvijaju i implementiraju svoje ideje. Svakako da u internom preduzetništvu ne treba zanemariti ni razvoj sistema komunikacije koji treba da bude potpuno transparentan, kako bi zaposleni mogli jedni sa drugima razmjenjivati informacije i podijeliti svoja iskustva.

Prednosti i nedostaci internog preduzetništva

Interno preduzetništvo ima svoje prednosti ali i nedostatke. Na osnovu sprovedenog istraživanja Badulescu (2013) je zaključio da se interno preduzetništvo pokazalo dobrim ne samo za poslodavca, već i za zaposlene, pošto zaposleni imaju priliku da se istaknu, pokažu svoje kvalitete, da se izdvoje, da budu inovatori. Takođe, kreativna, inovativna osoba koja je podstaknuta da koristi svoje lične kvalitete osjećaće se motivisano da ostane u kompaniji i stoga se fenomen, po kojem se vrijedni, otvoreni i inovativni zaposleni, razočarani organizacijama i birokratskim procesima prisutnim u srednjim velikim kompanijama, odlučuju dati otkaz, polako gubi (Badulescu, 2013).

Glavna prednost uspjele inovativnosti je ostvarenje profita nakon što istu prihvati tržište. Naravno da ostvarenje profita nije jedina benefit koju preduzeća imaju od internog preduzetništva. Naime, preduzeća koja podržavaju procese internog preduzetništva svojih zaposlenih na taj način dobijaju nove ideje, dijelove proizvodnih procesa, nove ili poboljšane proizvode, usluge i uopšteno nove vrijednosti unutar kompanije, što posljedično utiče na unaprijeđenje poslovanja. Pored toga, veoma bitan benefit internog preduzetništva, iz pozicije kompanija, jeste da se internim preduzetništvom ne stvara konkurencija već se pametnom stimulativnom politikom dobijaju saradnici. Naime, kompanije koje podržavaju preduzetnički duh svojih zaposlenih, od najboljih i najinovativnijih zaposlenih ne prave konkurenciju, već naprotiv, određenim stimulacijama, vjerne saradnike sa kojima mogu postići dugoročne uspjehe. U suprotnom, bi se moglo desiti da, zaposleni koji smatraju da se njihov rad potcjenjuje ili da kompanija ne ulaže dovoljno u njihovu edukaciju, pređu u konkurentsku kompaniju, ili da pokrenu svoj vlastiti poslovni biznis identičan ili sličan onom koji su ranije razvijali u preduzeću. Da se ovi rizici izbjegnu ili barem svedu na najmanju moguću mjeru, neophodno je razviti adekvatan sistem stimulacija koji predstavlja jednu od ključnih uloga razvoja korporativnog preduzetništva (Morris et al., 2008).

S druge strane, iz ugla zaposlenih, benefiti podržavanja internog preduzetništva su razvoj preduzetničkih znanja i vještina, mogućnost veće zarade, a time i povećana motivacija, koja podstiče kreativnost i inovativnost. Zaposleni čije ideje imaju podršku kompanije te svoje ideje pretvaraju u konkretne biznise na taj način postajući sve angažovaniji i produktivniji, iskazujući više zanimanja ka kreiranju i stvaranju nove vrijednosti unutar kompanije.

Postoji niz faktora koji predstavljaju prepreke razvoju kompanija u pravcu veće inovativnosti i kreativnosti zaposlenih. Jedan od ključnih razloga, zbog kojih se organizacije nerado odlučuju za implementaciju koncepta internog preduzetništva, jeste strah od gubitka kontrole nad poslovanjem. Naime, interno preduzetništvo podrazumijeva veću autonomiju zaposlenih u donošenju odluka i angažovanje na projektima koji nisu neposredno povezani sa svakodnevnim operativnim poslovanjem kompanije. Dodatno, prisutan je i strah od narušavanja funkcionalnosti organizacije, s obzirom na to da interno preduzetništvo često uključuje angažman na netipičnim ili rizičnim inicijativama. Konačno, prepreku može predstavljati i nedostatak finansijskih i drugih resursa. Kompanije takođe mogu imati problem sa finansiranjem internog preduzetništva, jer projekti koje pokreću zaposleni nerijetko zahtijevaju dodatna ulaganja čime se povećava opterećenje na postojeće kapacitete preduzeća. S obzirom da je prioritetni cilj bilo koje kompanije

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ostvarenje profita, logično je da kompanija očekuje da u u nekom vremenu povрати uložena sredstva i ostvari određenu zaradu, što bi svakako bio benefit za kompaniju.

STUDIJA SLUČAJA KOMPA NIJE VENDOM

Preduzeće “Vendom” d.o.o. Laktaši osnovano je 2003. godine. Bavi se proizvodnjom metalnih proizvoda za domaće i inostrano tržište, sa posebnim akcentom na razne vrste kontejnera za odlaganje otpada proizvedene za zemlje Evropske unije i Južne Amerike. Trenutno kompanija “Vendom” d.o.o. Laktaši ima oko 200 zaposlenih, sa godišnjim prihodom koji prelazi 20 miliona evra, i predstavlja jednog od najvećih izvoznika u metalnom sektoru u Bosne i Hercegovine. Najbitnije konkurentne prednosti preduzeća su: kratki rokovi isporuke, pouzdanost i kvalitet. Proizvodi preduzeća “Vendom” izdvajaju se svojim dizajnom, inovativnošću i kvalitetom, a prednosti saradnje sa ovom kompanijom od strane kupaca su odgovori na posebne zahtjeve klijenata, specifičnost proizvoda preduzeća, montaža, servis i održavanje proizvoda.

Paleta proizvoda ove renomirane kompanije kreće se od industrijskih i stambenih ograda, manjih čeličnih konstrukcija do 100 t, pa do zahtjevnih konstrukcija za industrijske potrebe do 1000 t. U paleti “Vendom” proizvoda posebno se izdvajaju paleta podzemnih i nadzemnih sistema za zbrinjavanje otpada, kao i kranova za pražnjenje kontejnera. Pored navedenog, kompanija nudi i konstrukcije, ograde, čelične kalupe, podzemne i nadzemne kontejnere za odlaganje otpada, čelične konstrukcije građevinskih objekata, različite proizvode od svih vrsta čelika proizvedeni prema zahtjevu kupaca ili rješenjima inženjera kompanije. Pored sopstvenih proizvoda kompanije, domaćem i inostranom tržištu nude se i usluge laserskog, plazmatskog i gasnog sječenja lima, savijanje lima, probijanje lima, varenje, pjeskarenje, praškasto farbanje, montaža, reparacija i rekonstrukcija, idejna rješenja, projektovanje i razvoj proizvoda prema zahtjevu kupca ili vlastitim idejnim rješenjima. Kompanija godišnje proizvode više od 2.500 nadzemnih i podzemnih kontejera za otpad, 50 kranova, 100.000 različitih metalnih proizvoda i više od 30 čeličnih konstrukcija.

Kompanija “Vendom” spada u red preduzeća koja već dugi niz godina, na obostrano zadovoljstvo, kod svojih zaposlenih podstiče interne preduzetničke inicijative. Naime, ova kompanija, kada je interno preduzetništvo u pitanju uglavnom se orijentiše na dva pravca:

- Podsticanje zaposlenih na preduzetničke inicijative koje se odnose na rješavanje neusaglašenosti i problema koje se javljaju u toku rada - proizvodnje ili primjedbe ili reakcije na implementaciju i prijedlozi za unaprijeđenje poslovnih procesa (engl. *bottom up* pristup – odozdo prema gore);
- dugoročni projekti koji se realizuju po osnovu inicijative višeg ili srednjeg menadžmenta (engl. *top down* pristup - odozgo prema dolje), ali i po osnovu inicijative pojedinca koji je menadžmentu predstavio svoju ideju/inovaciju/inicijativu i koji zatim učestvuje u realizaciji ideje sa timom, s tim da pokretač inicijative ne mora biti u strukturi u nivou višeg ili srednjeg menadžmenta.

Važno je naglasiti da kompanija 'Vendom', s obzirom na svoju organizacionu strukturu i viziju osnivanja, njeguje kulturu internog preduzetništva, aktivno podstičući zaposlene na inovativno razmišljanje i djelovanje. Ipak, kao što je već istaknuto u teorijskom dijelu rada, ovakav pristup može imati dvostruki efekat, donoseći istovremeno i potencijalne koristi i izazove za samo preduzeće.

U nastavku su navedeni neki primjeri internog preduzetništva u kompaniji „Vendom“.

Optimizacija procesa plaćanja

Na inicijativu finansijskog referenta optimizovano je plaćanje prema dobavljačima i isključeno (obustavljeno) je plaćanje privatnih finansijskih obaveza zaposlenih. Ovdje treba naglasiti da plaćanje u „Vendomu“ nije automatizovana procedura iz razloga što situacija na tržištu, a i potpisani ugovori u kojima su različita vremena plaćanja, zahtijevaju da finansijski direktor preduzeća donosi odluke o dugovanjima i potraživanjima. Prije izvršene optimizacije, plaćanja prema dobavljačima i knjiženja izvoda odvijala su se svakodnevno, što je uzrokovalo

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preopterećenost finansijskog referenta čiji je opis posla svakako već obiman. Svakodnevno plaćanje, što je procedura koja zahtijeva veliku koncentraciju, spriječavalo je ovog zaposlenog da bude dnevno operativan u potrebnom i zahtjevanom kapacitetu. Pored pomenutog, postojao je još jedan uzrok zagušenja ovog radnog mjesta - plaćanje rata kredita zaposlenima koji kasne sa ratama, a po osnovu sudskih presuda, kao i relativno često aktiviranje administrativnih zabrana koje je preduzeće ovjeravalo zaposlenima. Na inicijativu samog referenta preduzeće „Vendom“ prestalo je zaposlenima ovjeravati administrativne zabrane. Zanimljivo je napomenuti da takav potez nije izazvao nezadovoljstvo zaposlenih iako je postojala bojazan menadžmenta da će se tako nešto desiti. Takođe se plaćanje prema dobavljačima, sa svakodnevnog, prebacilo na plaćanje u sedam uzastopnih dana tokom mjeseca o čemu su dobavljači na vrijeme obavješteni i sa čim su bili potpuno saglasni. Rezultat nastalih promjena/inovacija bio je da se umnogome rasteretilo radno mjesto finansijskog referenta što je izvršiocu tog posla olakšalo radne poslove, povećalo dnevnu operativu, smanjilo mogućnost greške radi premora, te olakšalo komunikaciju sa finansijskim direktorom koja je do tada bila na dnevnom nivou, a od trenutka promjena svela se na nedeljnu. Dio preduzeća zadužen za finansije je osjetio značajno poboljšanje implementacijom ovih inovacija. Zaposleni koji je predložio promjene nije dobio finansijsku stimulaciju, ali je kao benefit dobio rasterećenje, svog radnog mjesta. Menadžment je evidentirao zaposlenog u bazu "inicijatora" i kada bude ponovo predložio procedure za poboljšanje postojećih procesa, dobiće adekvatnu finansijsku povišicu na zaradu. U navedenom slučaju radilo se o zaposlenom koji je predložio procedure za unaprijeđenje poslova vezano za jedno konkretno radno mjesto. U nastavku ćemo navesti primjer internog preduzetništva od strane srednjeg nivoa menadžmenta.

Robotizacija procesa proizvodnje

Na inicijativu srednjeg menadžmenta kompanija „Vendom“ započela je proces robotizacije dijela proizvodnje. Ovaj proces iniciran je sa projektnim timom od pet ljudi koji su radili na principu od ideje do realizacije, a odnosio se na proces zavarivanja prilikom kojeg je dolazilo do grešaka izazvanih u najvećem broju slučajeva ljudskim faktorom (nestručnost, premor, nekvalitetno i neprecizno zavarivanje i sl). Problem je dalje uzrokovao nepotrebne troškove, povećavanje otpadnog materijala, pa čak i škartiranje proizvoda. Implementacijom robotskog zavarivanja u proizvodni proces ostvarene su brojne prednosti (tabela 1).

Tabela 1. Prednosti robotizacije procesa zavarivanja u kompaniji „Vendom“

PROCES ZAVARIVANJA		
	Zavarivanje od strane zaposlenih	Robotizacija procesa
Nestručnost	Srednja do niska	Veoma niska
Kvalitet zavarivanja	Srednji do visok	Veoma visok
Faktor umor	Postoji	Ne postoji
Stepen ponovljivosti radnje	Ograničen	Neograničen
Preciznost	Srednja do visoka	Veoma visoka
Brzina	Srednja do visoka	Veoma visoka
Faznost	Više faza	Jedna faza
Rizik od povreda	Postoji	Ne postoji
Produktivnost	Srednja do visoka	Veoma visoka

Jedna od najznačajnijih prednosti robotskog zavarivanja bio je visok stepen ponovljivosti radnje i velika preciznost, čime se povećavala sposobnost procesa da proizvodi ujednačene visokokvalitetne proizvode u većim serijama, što je glavni preduslov za razvoj saradnje sa zahtjevnim evropskim tržištem. Pomenuta inovacija takođe je značajno povećala i produktivnost, s obzirom da se proces zavarivanja uvođenjem robotizacije izvodi brže i bez bilo kakvog prekida.

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Zahvaljujući ovoj inovaciji došlo je i do promjene sistematizacije radnih zadataka i to tako da se nekoliko radnih mjesta, na kojima su se ručnim zavarivanjem dobijali proizvodi u više faza pripojnog zavarivanja, spojilo u jedno. Na tom jednom radnom mjestu je sada, pomoću savremenih i precizno izrađenih pristroja (alata), omogućena izrada finalnog proizvoda u jednoj fazi (bez pripojnog zavarivanja). Konkretno, u ovom slučaju proizvodnog programa firme „Vendom“ produktivnost se povećala za oko 20%.

S obzirom da robotsko zavarivanje spada u savremenu tehnologiju, povećan je i broj kvalifikovanih i obučanih kadrova čime se povećala i kompetentnost i konkurentnost firme na tržištu, kao i mogućnost razvoja novih proizvoda bez prekidanja proizvodnog procesa (tzv. *offline* programiranje i simulacija). Robotizacija dijela proizvodnje donijela je određene benefite i za zaposlene, pogotovo za one koji su bili neposredno uključeni u proces zavarivanja. Naime, automatizovano robotsko zavarivanje smanjilo je zavarivačima rizik od povreda, s obzirom da su roboti preuzeli najveći dio rada koji se odvijao u opasnim ili nezdravim uslovima. U neposrednoj budućnosti, u kompaniji „Vendom“ se očekuje da će roboti preuzeti složene poslove zavarivanja stranica kontejnera, tako da će njegova proizvodnja uskoro biti 100% automatizovana. Da bi se to postiglo u prvoj polovini maja 2025. godine planirana je edukaciju za zaposlene koji će neposredno učestvovati u upravljačkim programima. Mogu se nabrojati benefiti koje je kompaniji „Vendom“ donijela ova inovacija u proizvodnji: povećana produktivnost, rasterećenje varijone, smanjena mogućnost greške, podignut kvalitet proizvoda, edukovani zaposleni koji su stekli nove vještine, povećani postojeći kapaciteti, automatizovan dio proizvodnje i dr. Uobičajeno je da u ovakvim slučajevima pokretač inicijative u kompaniji „Vendom“ napreduje u hijerarhiji i dobija stimulaciju u određenom novčanom iznosu, što se i bio rezultat ovog poduhvata.

Unaprijeđenje informacionog sistema preduzeća

Treći primjer internih preduzetničkih inicijativa, a koji se desio u kompaniji, vezan je za IT sektor. Naime, kompanija „Vendom“ je dugo vremena kao ERP (engl. *Enterprise Resource Planning*) sistem koristila *Pantheon*, odnosno poslovni informacioni sistem prilagođen za brzo rastuća preduzeća. Radi se o stabilnom sistemu koji ima napredne funkcionalnosti i široku prilagodljivost. Baš taj širok izbor funkcionalnosti omogućava da sistem koriste svi, od rukovodilaca, do radnika zaduženih za nabavke i računovodstvo. Na inicijativu projekt menadžera – zaposlene, koja je zadužena i nadležna za nekoliko različitih projekata u preduzeću, *Pantheon* je modifikovan i unaprijeđen sa dodatnom modulom koji je donio direktne benefite sektorima nabavke i proizvodnje. Konkretno, prije nadogradnje sistema ulaz materijala: toplo i hladno valjanih limova, aluminijuma, pocinčanog lima i nehrđajućeg čelika, bio je definisan samo u kilogramima, što je dovodilo do dvije vrste problema koji su posebno bili vezani za dva pomenuta sektora. Sektor nabavke je dobijao zahtjeve iz proizvodnje za nabavku lima, ali u broju tabli, a ne u kilogramima, dok Sektor proizvodnje, gdje se materijal sa stanja nakon sječenja skidao u kilogramima, nije imao informaciju koliko tabli je ostalo na stanju za dalje sječenje. Obje situacije dovodile su do gomilanja lima koji nije bio precizno evidentiran na pomoćnom lageru koji se nalazio na otvorenom prostoru. S obzirom na takvu situaciju kompanija je imala ne samo novčane gubitke, već je nabavljala i plaćala materijal koji je imala na stanju. Dodatno, zbog ovog problema nije postojala mogućnost transformacije otpadnih tabli u dodatnu količinu pozicija, što je kasnije bio slučaj. I ovaj problem riješen je inicijativom projekt menadžera koji je predložio da se dodatnom aplikacijom u postojećem ERP-u obezbijedi unos materijala u kilogramima i tablama, što je softverski i riješeno. Na kraju je projekt menadžer nagrađen novčanom stimulacijom, a kompanija je napravila nemale uštede i smanjila otpadni materijal.

Izazovi vezani za interno preduzetništvo

Kao što je već istaknuto u teorijskom dijelu rada, podsticanje internog preduzetništva može imati dvostruki efekat, donoseći istovremeno i potencijalne koristi i izazove za samo preduzeće. Naime, podsticanjem preduzetničke inicijative i davanjem alata zaposlenima postoji potencijalna opasnost da kompanija sebe dovede u nepovoljnu situaciju.

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Nakon što kompanija uloži sredstva u edukaciju zaposlenih a zaposleni stekne neophodno znanje, iskustvo i pristup alatima, može doći do situacije u kojoj zaposleni napušta organizaciju i osniva sopstveni biznis, često proizvodeći identične ili slične proizvode kao matična kompanija čime direktno ulazi u konkurentski odnos sa njom. Takođe, nisu rijetki slučajevi u kojima zaposleni, uprkos očiglednom sukobu interesa, prenose sva svoja stečena znanja i prethodne inicijative zapošljavajući se u konkurentske kompanije.

ZAKLJUČAK

Rad koji je prikazan predstavio je mogućnosti podsticanja internih preduzetničkih inicijativa kod zaposlenih na primjeru proizvodne kompanije “Vendom”. Studija slučaja je obuhvatila tri primjera internih inicijativa zaposlenih. Rezultat optimizacije procesa plaćanja bio je da se u mnogome rasteretilo radno mjesto finansijskog referenta što je izvršiocu tog posla olakšalo radne poslove, povećalo dnevnu operativu, smanjilo mogućnost greške radi premora, te olakšalo komunikaciju sa finansijskim direktorom. S druge strane automatizovano robotsko zavarivanje smanjilo je zavarivačima rizik od povreda, s obzirom da su roboti preuzeli najveći dio rada koji se odvijao u opasnim ili nezdravim uslovima. Na kraju, modifikacijom se došlo do unaprijeđenja informacionog sistema preduzeća, što je donijela direktne benefite Sektoru nabavke i Sektoru proizvodnje. Ove aktivnosti ilustruju praktičnu primjenu inovacija unutar organizacije s ciljem povećanja efikasnosti, smanjenja troškova i jačanja konkurentске pozicije na tržištu.

Može se zaključiti da i pored toga što sa sobom nosi određene rizike prethodno opisane u okviru studije slučaja, primjera radi kada zaposleni u čiju edukaciju je kompanija uložila značajna sredstva napušta preduzeće i osniva sopstveni biznis, interno preduzetništvo predstavlja odličnu mogućnost da se iskoristi potencijal postojećih ljudskih resursa pri kreiranju nove vrijednosti, bez obzira da li inicijativa za uvođenje inovacije dolazi od pojedinca ili dijela menadžmenta. Da bi se ostvarila zamisao potreban je timski rad i puna podrška organizacionih dijelova kompanije, što je i pokazano na tri realna primjera internih preduzetničkih inicijativa implementiranih u kompaniji „Vendom“. Sve navedene inicijative bile su pokrenute i realizovane od strane zaposlenih u kompaniji i ostvarile su benefite kako u unaprijeđenju operativnih performansi rada tako i u finansijskim pokazateljima poslovanja.

Bitno je napomenuti da su ove uspješno ostvarene interne inicijative kompaniji “Vendom” donijele niz benefita koji su se manifestovali kroz povećanu produktivnost, rasterećenje najopterećenijeg dijela kompanije, smanjenu mogućnost greške u proizvodnji, podignut kvalitet proizvoda, povećan broj edukovanih zaposlenih koji su stekli nove vještine, povećane postojeće kapacitete, povećan automatizovan dio proizvodnje i dr. Zaposleni koji su pokazali inovativnost bili su adekvatno nagrađeni, što je rezultiralo povećanjem njihovog zadovoljstva, a samim tim i rastom ukupne produktivnosti. .

Prikazane inicijative predstavljaju odličan primjer dobre prakse osnaživanja i iskorišćenja preduzetničkog potencijala zaposlenih, što je donijele značajne benefite, kako za kompaniju, tako i za same zaposlene. Budući pravci istraživanja mogli se odnositi na dalje unaprijeđenje i strukturisanje inicijativa korporativnog preduzetništva u cilju maksimizacije preduzetničkog potencijala kompanije, iskorištavanje prednosti koje korporativno preduzetništvo donosi uz istovremeno adekvatno ophođenje prema identifikovanim rizicima.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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OPPORTUNITIES FOR ENCOURAGING INTERNAL ENTREPRENEURIAL INITIATIVES AMONG EMPLOYEES IN MANUFACTURING COMPANIES – CASE STUDY OF THE COMPANY VENDOM

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ABSTRACT

Internal entrepreneurship refers to a process based on the creation of innovative ideas within existing companies with the aim of improving business strategy and achieving long-term success. Creative and innovative solutions arising from the concept of internal entrepreneurship represent a new product, a new service, or a new value that the organization can deliver to other companies. Employee innovativeness largely emerges as a result of individual characteristics, which should represent a significant potential for any company.

The subject of this paper is entrepreneurial initiatives and the possibilities for encouraging them within companies. To that end, the paper presents a case study of a company in the metal industry, showcasing examples of internal entrepreneurial initiatives.

Despite certain risks and challenges that may accompany individual entrepreneurial initiatives by employees, the conclusion is that companies can gain multiple benefits and that the future of modern business must support employee innovativeness through the encouragement and stimulation of their ideas.

Keywords: internal entrepreneurship, manufacturing company, key factors, innovation, management.

STRATEŠKA ULOGA USLUŽNOG AMBIJENTA U PROCESU OSTVARIVANJA KONKURENTSKE PREDNOSTI NA PRIMJERU KOMPANIJE KRAŠ

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SAŽETAK

U savremenom poslovnom okruženju, gdje su tradicionalne metode diferencijacije sve manje efikasne, strateško upravljanje uslužnim ambijentom postaje ključno za održavanje konkurentske prednosti. Kroz strateški kreiran uslužni ambijent preduzeća mogu direktno uticati na oblikovanje percepcije potrošača, stvarajući pozitivno iskustvo koje se prenosi na cjelokupan brend. Razumijevanje i strateška primjena elemenata uslužnog ambijenta omogućava preduzećima da se, unapređujući korisničko iskustvo i jačajući emocionalnu vezu sa potrošačima, jasno izdvoje na tržištu. Ovaj pristup omogućava preduzećima da transformišu svakodnevne interakcije u ključne tačke lojalnosti i povjerenja, čime se ne samo jača reputacija brenda, već se i osigurava njegova dugoročna održivost na tržištu. Cilj istraživanja ovog rada predstavlja analiza uticaja uslužnog ambijenta na percepciju brenda i zadovoljstvo potrošača, kao i načina na koji strateška primjena njegovih elemenata može doprinijeti jačanju konkurentske prednosti i dugoročnom poslovnom uspjehu kompanije Kraš. Naučno-istraživački karakter ovog rada počiva na analizi relevantne naučne literature i savremenih izvora korišćenjem metoda analize, komparacije, ispitivanja, deskripcije i dedukcije. Rezultati empirijskog istraživanja pokazali su da strateški osmišljen uslužni ambijent značajno doprinosi ostvarivanju konkurentske prednosti kompanije Kraš, utičući na povećanje korisničkog zadovoljstva, prepoznatljivost brenda i ukupne poslovne performanse.

Ključne reči: strateški menadžment, uslužni ambijent, Kraš.

UVOD

Uslužni ambijent predstavlja okruženje u kojem se pruža usluga i uključuje sve što je opipljivo, a utiče na iskustvo korisnika usluga tokom procesa pružanja usluge (Bitner, 1992). Sa marketinške tačke gledišta, uslužni ambijent pruža kupcima uvid u vrstu usluge koju mogu očekivati, kao i u tip i kvalitet dostupnih proizvoda, u skladu sa očekivanjima ciljnog tržišta. Iako se često ne pravi razlika između termina "atmosfera" i "ambijent" važno je razumjeti da ambijent predstavlja osnovu za stvaranje atmosfere i da ambijent svojim djelovanjem postavlja temelje na kojima se razvija atmosfera. Atmosfera uključuje različite elemente koji se oblikuju i kojima se upravlja unutar prodajnog prostora sa ciljem izazivanja specifičnih emocija i ponašanja kod potrošača (Jain, & Weiten, 2020). Na osnovu toga, može se zaključiti da potrošač ne kupuje samo proizvod i njegove materijalne karakteristike, već i dio ukupnog ambijenta. Glavni cilj ambijenta je da izazove određene emocije i ponašanja koja mogu dovesti do produženog boravka u prodajnom prostoru ili povećane kupovine. Takođe, ambijent treba biti usklađen sa vrstom usluge koja se pruža. Ugodan i privlačan uslužni ambijent proizlazi iz kombinacije elemenata koji djeluju na ljudska čula. Ti elementi obuhvataju osvetljenje, boje, dimenzije i oblike, zvukove, temperaturu i mirise (Baker, Bentley, & Lamb, 2020). Kada se kreira ambijent, preduzeća imaju na raspolaganju različite faktore koji se mogu prilagoditi specifičnim potrebama. Važno je naglasiti da se ti elementi doživljavaju ne samo pojedinačno, već i kao cjelina. Zbog prethodno navedenog ključno je ne zanemariti nijedan faktor, ali i izbjegavati prekomjernu upotrebu kako bi se spriječile neželjene reakcije potrošača. Osim toga, različiti elementi mogu različito uticati na pojedince, izazivajući različite utiske. Strateški osmišljen uslužni ambijent ne utiče samo na korisnike, već i

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na zaposlene (Kaminakis, et al., 2019). Prijatan i funkcionalan radni prostor može poboljšati produktivnost, zadovoljstvo i motivaciju zaposlenih, što u krajnjoj liniji utiče na kvalitet usluge i odnose sa korisnicima (Muslih, & Damanik, 2022). U tom smislu, predmet istraživanja ovog rada jeste analiza strateškog značaja uslužnog ambijenta za kompaniju Kraš, sa posebnim fokusom na njegove ključne elemente. Cilj istraživanja ovog rada je pružiti sveobuhvatan uvid u uticaj uslužnog ambijenta na percepciju brenda i zadovoljstvo potrošača, kao i analizirati na koji način strateška primjena njegovih elemenata može doprinijeti jačanju konkurentske prednosti i dugoročnom poslovnom uspjehu kompanije Kraš. Na osnovu predmeta i ciljeva istraživanja, postavljene su sledeće hipoteze:

- H1: Strateški osmišljen uslužni ambijent značajno doprinosi ostvarivanju konkurentske prednosti kompanije Kraš, utičući na povećanje korisničkog zadovoljstva, prepoznatljivost brenda i ukupne poslovne performanse.
- H2: Implementacija strateški osmišljenih elemenata uslužnog ambijenta poboljšava korisničko iskustvo i utiče na veću lojalnost potrošača, što dovodi do povećane učestalosti posjeta i kupovina.
- H3: Strateška primjena elemenata uslužnog ambijenta omogućava stvaranje diferencirane atmosfere koja utiče na percepciju brenda i percepciju vrijednosti proizvoda, što doprinosi jačanju konkurentske prednosti na tržištu.

ANALIZA USLUŽNOG AMBIJENTA KOMPANIJE KRAŠ

Uslužni ambijent kompanije Kraš predstavlja ključni element u stvaranju sveukupnog doživljaja potrošača. Eksterijer Kraševih radnji pokazuje dosljednost u brendiranju i estetskom pristupu. Upotreba dvije dominantne kombinacije boja na eksterijerima radnji jasno komunicira različite aspekte brenda stvarajući snažan vizuelni identitet. Kombinacija bijele i zlatne boje naglašava prestiž, luksuz i čistoću, čim se naglašava da su proizvodi vrhunskog kvaliteta namijenjeni kupcima koji traže jedinstvenost. Kombinacija crvene i smeđe boje korespondira sa temom brenda i evocira asocijacije na čokoladu i druge Kraševe proizvode. Ova paleta boja ne samo da oslikava identitet brenda, već i pobuđuje pozitivne asocijacije na proizvode po kojima je Kraš poznat. Jasno istaknut naziv radnje i logotip osiguravaju visoku prepoznatljivost brenda i omogućavaju kupcima da ih lako primijete čak i sa veće udaljenosti. Minimalistički pristup eksterijera doprinosi dosljednosti i harmoniji u vizuelnom identitetu brenda. Ulazna vrata i stakleni izlog doprinose modernom i prefinjenom izgledu pružajući diskretan uvid u unutrašnjost radnje, što podstiče radoznalost i poziva kupce da istraže ponudu. Odsustvo suvišnih dekoracija i jednostavan dizajn pružaju da fokus ostane na proizvodima i brendu, što je ključan element u privlačenju pažnje i zadržavanju interesa prolaznika (Sachdeva, & Goel, 2015). Ukupni utisak eksterijera sugerise pažljivo osmišljen vizuelni identitet, koji balansira između modernog i tradicije, pružajući brendu mogućnost da istakne svoju ponudu na nenametljiv, ali upečatljiv način. Interijer kompanije Kraš je osmišljen tako da pruža prijatan vizuelni doživljaj koristeći tople boje koje asociiraju na tradiciju i kvalitet. Arhitektonska rješenja su moderna, ali sa elementima koji naglašavaju dugogodišnju istoriju brenda. U dizajnu interijera Kraševih prodavnica dominantne su tople nijanse boja poput zlatne, smeđe i bijele, što odaje osećaj luksuza i sofisticiranosti (Cho, & Lee, 2017). Ove boje su pažljivo odabrane da istaknu ekskluzivnost proizvoda, kao i da kreiraju prijatno okruženje za kupovinu. Bijele police sa diskretnim osvjetljenjem iza proizvoda dodatno osvjetljava iste stavljajući ih u prvi plan.

Posmatrano iz ugla klasifikacije logotipa, logotip kompanije Kraš pripada kombinaciji grafike i tipografskih elemenata. Tipografijom je dopunjen vizuelni identitet, koji je naglašen grafičkim rješenjem (Özkul, Bilgili, & Koç, 2020). Ovalni oblik je klasičan izbor za brendove sa dugom tradicijom, jer stvara osećaj postojanosti i sigurnosti. Oko ovala se nalaze dekorativni elementi koji pojačavaju osjećaj elegancije i sofisticiranosti. Tipografija je jednostavna, ali efektna sa velikim i podebljanim slovima. Tipografija je prepoznatljiv dio Kraša i ostala je nepromijenjena u odnosu na prvu verziju logotipa. Na logotipu kompanije Kraš zastupljena je topla crvena boja, koja budi energičnost i podstiče potrošače na akciju.

U prodajnim objektima kompanije Kraš može se uvidjeti prigušen stepen rasvjete što može uticati na potrošače da spuste oprez i kupuju iz užitka, a ne iz praktičnih razloga. Kombinacija toplih tonova akcentnog osvijetljenja sa neutralnim tonovima enterijera omogućava stvaranje prijatnog i elegantnog ambijenta, koji ne samo da osvjetljava prostor, već i naglašava osnovne vizuelne elemente dizajna, što doprinosi potpunom doživljaju kupaca. Muzika koja se emituje u ovim objektima pažljivo je odabrana kako bi se stvorila prijatna i inspirativna atmosfera koja odražava brend i vrijednosti kompanije. Najzastupljeniji žanr muzike u prodajnim objektima kompanije Kraš je pop muzika. Ovaj žanr je poznat po svojoj energiji i ritmičnosti, što doprinosi stvaranju dinamične i privlačne atmosfere (Andersson et al., 2012). Pop muzika je prepoznatljiva po svojoj brzini i korišćenju različitih instrumenata i ritmova, što je u skladu sa živahnim i modernim imidžom koji Kraš želi da promoviše. Brzi tempo i prijatni ritmovi pop muzike mogu poboljšati raspoloženje kupaca, čineći njihov boravak u prodajnim objektima prijatnijim i opuštajućim.

Mirisni stimulansi igraju ključnu ulogu u stvaranju prijatnog i privlačnog uslužnog ambijenta u prodajnim objektima kompanije Kraš. U Kraševim prodajnim objektima miris svježe čokolade može se osjetiti gotovo odmah po ulasku, stvarajući topao i primamljiv ambijent. Ovaj miris ne samo da evocira osećaj nostalgije i udobnosti kod potrošača, već može podstaći apetit i želju za kupovinom snažno djelujući na emocije i donošenje odluka. Kupci koji osjećaju miris čokolade vjerovatnije će kupiti više proizvoda ili impulsivno odabrati nešto što možda nisu planirali. Miris čokolade kod većine potrošača izaziva zadovoljstvo i uzbuđenje (Knasko, 1995) i mijenja ponašanje posjetioca u prodajnom objektu. Mattila i Wirtz (2001) su utvrdili da zastupljenost mirisa čokolade u prodajnom objektu navodi kupce da sam proizvod pogledaju više puta, zbog čega su čak tri puta više spremni da izvrše interakciju sa osobljem.

Taktilni stimulansi doprinose opštem doživljaju prostora kroz fizički kontakt sa različitim materijalima i površinama (Orth, Heinrich, & Malkewitz, 2012). U prodavnicama kompanije Kraš posebna pažnja posvećena je teksturama korišćenim u dizajnu prostora. Glatke, sjajne površine staklenih polica i pulta pružaju osjećaj čistoće i urednosti, dok upotreba luksuznih materijala poput mermerske ili sjajnih keramika doprinosi stvaranju premium atmosfere. Dizajnerski pristup pažljivo kombinuje ove taktilne elemente sa funkcionalnošću, osiguravajući da prostor bude prijatan kako za vizuelni, tako i za fizički kontakt, što doprinosi cjelokupnom doživljaju kupaca u interakciji sa proizvodima.

MATERIJAL I METODE RADA

Naučno-istraživački karakter ovog rada počiva na analizi relevantne naučne literature i savremenih izvora korišćenjem metode ispitivanja, metode analize, metode komparacije, metode deskripcije i metode dedukcije. Problem istraživanja ovog rada odnosi se na identifikovanje i analizu ključnih aspekata uslužnog ambijenta i njihove strateške uloge u procesu ostvarivanja konkurentne prednosti. S obzirom na to da su elementi uslužnog ambijenta često zanemareni u tradicionalnim analizama konkurentne prednosti, svrha istraživanja je da se istraže njihovi specifični uticaji na ponašanje potrošača i evaluiira njihova važnost za kompaniju Kraš. Istraživanje će doprinijeti boljem razumijevanju kako optimizacija uslužnog ambijenta može pomoći u jačanju pozicije preduzeća na tržištu i ostvarivanju dugoročne konkurentne prednosti. Kao glavna metoda za prikupljanje podataka korišćena je metoda ispitivanja, a kao instrument anketa. Anketoiranje je vršeno online putem, a veličina uzorka ispitivanja se sastojala od 181 ispitanika nastanjenog na području Republike Srpske, koji su upoznati sa brendovima kompanije Kraš. Anketoiranje je sprovedeno u mesecu avgustu 2024. godine.

REZULTATI I DISKUSIJA

Od ukupnog uzorka istraživanja, 66.7% ispitanika je ženskog pola, a 33.3% ispitanika muškog pola. Najveći procenat ispitanika 70.6% starosti između 15 i 24 godine. S obzirom da proizvodi koji su tema istraživanja nisu osnovne životne namirnice i rjeđe se kupuju, najveći procenat ispitanika 29.4% Kraševe proizvode konzumira jednom mjesečno. Kada je u pitanju lojalnost potrošača, 90.2% ispitanika Kraševe proizvode konzumira duže od 3 godine, što je i

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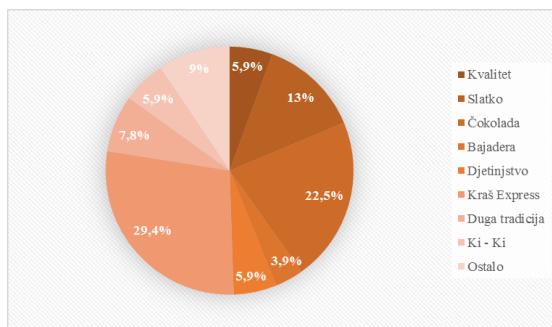
očekivan podatak s obzirom na to da je Kraš već dugi niz godina vodeći konditorski proizvođač u Jugoistočnoj Evropi zahvaljujući kvalitetu, tradiciji i snažnim brendovima.

Tabela 1. Zadovoljstvo potrošača proizvodima kompanije Kraš na osnovu datih faktora.

Table 1. Consumer satisfaction with Kraš company products based on given factors.

OCJENA	1 – veoma nezadovoljan	2 – nezadovoljan	3 – nemam mišljenje	4 – zadovoljan	5 – Veoma zadovoljan
Kvalitet/ukus	2%	5,9%	2%	23,5%	66,6%
Širina asortimana	-	5,9%	5,9%	45,1%	43,1%
Cijena	-	9,8%	25,4%	37,3%	27,5%
Pakovanje	2%	7,8%	15,7%	33,3%	41,2%

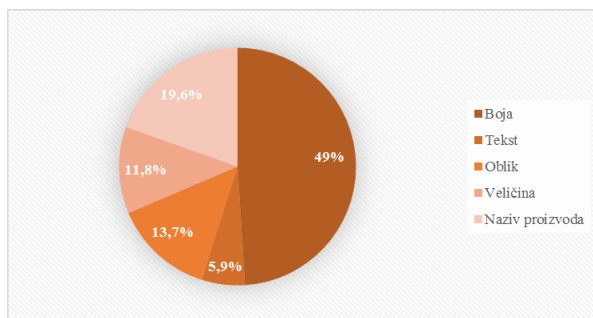
Podaci iz tabele 1 prikazuju stavove potrošača o zadovoljstvu proizvodima kompanije Kraš. Najistaknutiji faktor je kvalitet i ukus, gdje čak 90.3% ispitanika izražava zadovoljstvo. Širinom asortimana je zadovoljno 88.2% ispitanika što ukazuje na činjenicu da raznovrsnost ponude zadovoljava širok spektar potrošačkih preferencija. Iako cijena nije najistaknutiji faktor zadovoljstva, stabilna ocjena ukazuje na činjenicu da 64.8% ispitanika smatra cijene razumnim u odnosu na kvalitet proizvoda. U korist prethodna dva rezultata ide i podatak da nijedan ispitanik nije nezadovoljan širinom asortimana ili cijenom. Pakovanjima proizvoda kompanije Kraš zadovoljno je 74.5% ispitanika. Ovi podaci ukazuju na činjenicu da Kraš ima stabilnu bazu zadovoljnih potrošača, sa ključnim prednostima u kvalitetu i ukusu, kao i širini asortimana, dok cijena i pakovanje dodatno podržavaju ukupno pozitivno iskustvo.



Grafikon 1. Asocijacije na kompaniju Kraš.

Graph 1. Associations with Kraš company.

Podaci iz grafikona 1 pokazuju različite asocijacije koje ispitanici vežu sa kompanijom. Za najveći procenat ispitanika 29.4% Kraš Express predstavlja prvu asocijaciju na kompaniju, dok se 22.5% ispitanika automatski sjeti čokolade. Takođe, za 15% ispitanika prva asocijacija je riječ "slatko", a 7.8% povezuje Kraš sa dugom tradicijom, što potvrđuje reputaciju brenda kao dugogodišnjeg lidera u industriji. Ostale asocijacije uključuju proizvode poput Ki-Ki bombona 5.9%, Bajadere 3.9%, Domaćice 2.3% i Peperminta 2.1%, naglašavajući prepoznatljivost pojedinih artikala u širokom asortimanu. Povezanost sa kvalitetom i osjećajem djetinjstva navelo je 5.9% ispitanika čime se dodatno naglašava emocionalna veza ispitanika sa brendom. Manji procenat ispitanika 1.8% povezuje Kraš sa Hrvatskom, a asocijacije poput "neodoljivo" 1.5% i "širok asortiman" 1.9% potvrđuju raznolikost i privlačnost brenda. Prethodno navedeni podaci ukazuju na snažnu emocionalnu povezanost potrošača sa kompanijom Kraš, koja je najčešće izražena kroz asocijacije na specifične proizvode, tradiciju i osjećaj djetinjstva, čime se dodatno potvrđuje značaj i prepoznatljivost brenda na tržištu.



Grafikon 2. Najupečatljiviji elementi proizvoda.
Chart 2. The most impressive elements of the product.

Analizirajući dobijene podatke iz grafikona 2, može se uvidjeti da 49% ispitanika najviše pažnje posvećuje boji proizvoda sugerišući da je vizuelni aspekt ključan faktor u privlačenju potrošača. Sljedeći po značaju je naziv proizvoda koji privlači 19.6% ispitanika, dok je oblik proizvoda važan za 13.7% ispitanika. Veličina proizvoda privlači 11.8% ispitanika, a tekst na ambalaži ima najmanji uticaj sa 5.9%.

Tabela 2. Zadovoljstvo potrošača elementima vizuelnog identiteta kompanije Kraš.

Table 2. Consumer satisfaction with elements of the visual identity of the Kraš company.

OCJENA	1 – uopšte mi se ne sviđa	2 – djelimično mi se ne sviđa	3 – nemam mišljenje	4 – djelimično mi se sviđa	5 – u potpunosti mi se sviđa
Boje	3,9%	11,8%	27,5%	29,3%	27,5%
Logotip	-	13,7%	17,7%	33,3%	35,3%
Oblik	5,9%	7,8%	21,5%	37,3%	27,5%
Slogan	-	11,8%	17,6%	21,6%	49%
Tipografija (tekst)	-	13,7%	29,4%	25,5%	31,4%
Cjelokupan vizuelni identitet	-	5,9%	33,3%	33,3%	27,5%

Podaci iz tabele 2 prikazuju stavove potrošača o elementima vizuelnog identiteta kompanije Kraš. Većini ispitanika 56.8% se u potpunosti ili djelimično sviđaju boje elemenata vizuelnog identiteta. Logotip je ocijenjen najvišom prosječnom ocjenom, gdje se 68.6% ispitanika ovaj element vizuelnog identiteta djelimično i u potpunosti dopada. Na drugom mjestu su oblik 64.8% i tipografija 56.9% sa djelimičnim ili potpunim zadovoljstvom ispitanika. Čak 60,8% ispitanika navodi da im se cjelokupan vizuelni identitet djelimično ili u potpunosti sviđa. Prethodni rezultati ukazuju da je zadovoljstvo vizuelnim identitetom uglavnom pozitivno, ali postoji značajan procenat ispitanika koji su neutralni prema cjelokupnom identitetu, što ostavlja prostora za dalje unapređenje.

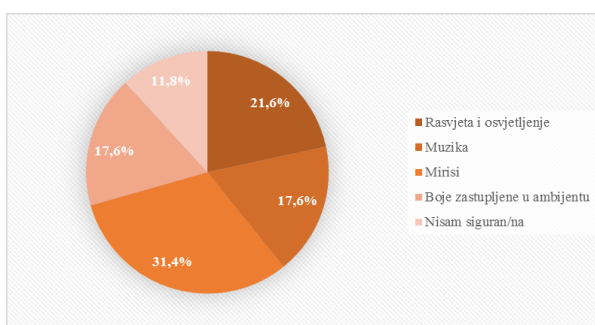
Podaci iz tabele 3 prikazuju stavove potrošača o vizuelnom identitetu kompanije Kraš. Najveći procenat ispitanika 56.8% se u potpunosti ili djelimično slaže da je vizuelni identitet kompanije lako pamtljiv ukazujući na visoku prepoznatljivost ovog elementa. Elegantan izgled vizuelnog identiteta potvrđuje 51% ispitanika, što sugerise da brend uspješno prenosi sofisticiranost kroz svoj dizajn. Međutim, vizuelni identitet nije posebno izražen u buđenju gladi, jer je 39.3% ispitanika ostalo neutralno prema ovoj tvrdnji. Skoro polovina ispitanika 49% smatra da se vizuelni identitet kompanije Kraš dobro uklapa u njihov stil života, dok 47.1% ispitanika povezuje vizuelni identitet sa pozitivnim uspomenama, što pokazuje emocionalnu vezanost potrošača prema brendu. Većina ispitanika 52.9%, smatra da vizuelni identitet zadovoljava njihova očekivanja, dok 39.2% ispitanika vjeruje da je vizuelni identitet vrijedan svoje cijene.

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Tabela 3. Stavovi potrošača o vizuelnom identitetu kompanije Kraš.

Table 3. Consumers' views on the visual identity of the Kraš company.

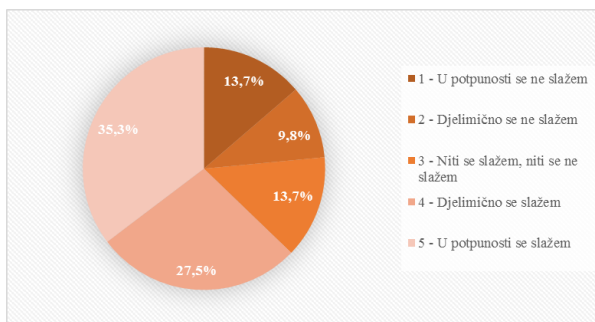
SKALACIJA	1 – uopšte se ne slažem	2 – djelimično se ne slažem	3 – nemam mišljenje	4 – djelimično se slažem	5 – u potpunosti se slažem
je lako pamtljiv	5,9%	11,8%	25,5%	21,5%	35,3%
je elegantan	3,9%	15,7%	29,4%	27,5%	23,5%
budi glad	11,8%	13,7%	39,3%	21,5%	13,7%
podstiče na kupovinu	9,8%	19,6%	37,3%	19,6%	13,7%
je prilagodljiv i odgovara mom stilu života	7,8%	5,9%	37,3%	31,4%	17,6%
uz kojeg vežem pozitivne emocije	9,8%	13,7%	29,4%	15,7%	31,4%
zadovoljava moja očekivanja	5,9%	11,8%	29,4%	31,4%	21,5%
za kojeg se isplati više platiti	11,8%	13,7%	35,3%	23,5%	15,7%



Grafikon 3. Najbitniji elementi uslužnog ambijenta prilikom kupovine.

Chart 3. The most important elements of the service environment when shopping.

Podaci iz grafikona 3 pokazuju da najveći procenat ispitanika 31.4% smatra mirise kao najbitniji element pri obavljanju kupovine. Nešto manji procenat ispitanika 21.6% smatra da su to rasvjeta i osvjetljenje, zatim muzika i boje sa po 17,6% ispitanika. Međutim, 11.8% ispitanika nije sigurno koji je element najbitniji. Prethodni podatak ukazuje na činjenicu da postoje različite preferencije među potrošačima kada je riječ o uslužnom ambijentu, ali i naglašava važnost stvaranja prijatnog i stimulativnog ambijenta tokom kupovine, pri čemu mirisi igraju ključnu ulogu u iskustvu kupaca.

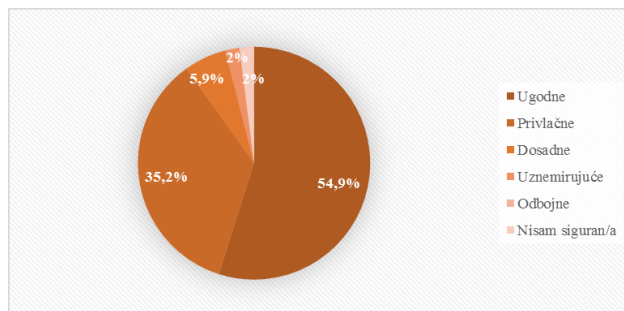


Grafikon 4. Stavovi potrošača o povezanosti boja i ljudskih emocija.

Chart 4. Consumer attitudes about the connection between colors and human emotions.

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Grafikon 4. prikazuje stavove potrošača o povezanosti boja sa ljudskim emocijama. Najveći procenat ispitanika 62.8% vjeruje u povezanost boje sa ljudskim emocijama. Prethodni podatak naglašava važnost boje kao ključnog elementa u dizajnu i marketingu, sugerišući da brendovi mogu koristiti boje strateški, kako bi evocirali željene emocionalne reakcije kod potrošača. Takođe, 23.5% ispitanika u potpunosti ili djelimično je protiv ove ideje, dok 13.7% ispitanika zauzima neutralan stav.



Grafikon 5. Ambijentalne boje prodajnih objekata kompanije Kraš.
Chart 5. Ambient colors of sales facilities of Kraš company.

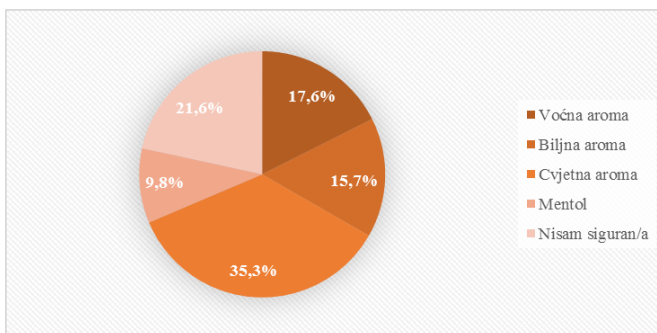
Posmatrajući rezultate na grafikonu 5 može se vidjeti da najveći procenat ispitanika doživljava ambijentalne boje prodajnog objekta kompanije Kraš kao pozitivne, pri čemu ih 54.9% opisuje kao ugodne, a 35.2% kao privlačne. Ovi podaci sugerišu da boje u ambijentu kompanije Kraš uspješno doprinose prijatnom iskustvu kupovine. Manji procenat ispitanika ih doživljava negativno, sa 5.9% onih koji smatraju boje dosadnim i 2% koji ih vide kao uznemirujuće. Samo 2% ispitanika nije sigurno u doživljaj ambijentalnih boja kompanije Kraš.

Tabela 4. Stavovi potrošača o zastupljenosti muzike u prodajnom objektu.

Table 4. Consumers' views on the representation of music in the sales facility.

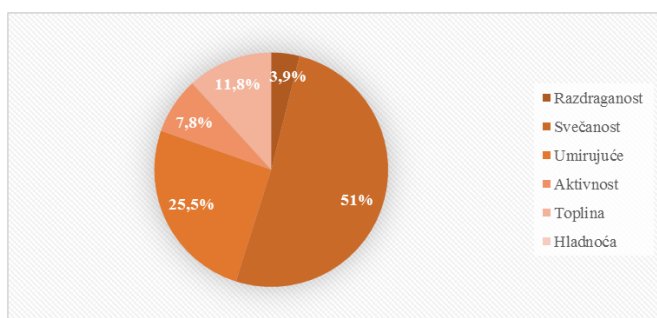
SKALACIJA	1 – uopšte se ne slažem	2 – djelimično se ne slažem	3 – nemam mišljenje	4 – djelimično se slažem	5 – u potpunosti se slažem
Nije mi bitno koja vrsta muzike je zastupljena u prodajnom objektu	29,4%	25,5%	23,5%	11,8%	9,8%
Duže ću se zadržati u prodajnom objektu ukoliko je muzika u pozadini prijatna	3,9%	1,9%	27,5%	37,3%	29,4%
Imam više strpljenja pri čekanju u redu za plaćanje ukoliko je u pozadini prijatna muzika	5,9%	7,8%	25,5%	23,5%	37,3%

Podaci iz tabele 4 ukazuju da veći procenat ispitanika 54.9% pridaje važnost muzici koja se pušta u prodajnom objektu, dok se 66.7% ispitanika slaže sa tvrdnjom da će duže ostati u prodajnom objektu ukoliko je muzika prijatna, a 60.8% ispitanika smatra da muzika može pozitivno uticati na njihovo strpljenje dok čekaju u redu za plaćanje. Ovi podaci potvrđuju činjenicu da pažljiv izbor muzike može doprinijeti poboljšanju ukupnog iskustva kupovine i zadovoljstvu kupaca.



Grafikon 6. Prijatnost pri kupovini u odnosu na zastupljenu aromu.
Graph 6. Pleasantness when shopping in relation to the represented aroma.

Razmatrajući podatke iz grafikona 6, najveći procenat ispitanika 35.3% se najprijetnije osjeća pri kupovini kada je u prodajnom objektu prisutna cvjetna aroma. Cvjetna aroma je jedna od onih koje se u prodajnim objektima kompanije Kraš može osjetiti, a koja na kupce utiče tako što im pomaže da se osvježe, živnu i ugodnije osjećaju. Nešto manji procenat ispitanika 17.6% izjasnio se da je voćna aroma najprijetnija, 15.7% biljna aroma, dok je najmanje preferirana aroma 9.8% mentol. Značajan procenat ispitanika 21.6% nije siguran u svoj izbor. Budući da je percepcija mirisa subjektivna i individualna, a često i podložna promjenama u zavisnosti od okruženja ili trenutnog emocionalnog stanja (Rimkute, Moraes, & Ferreira, 2016), ispitanici mogu osjećati nesigurnost, jer nemaju jasnu svijest o tome kako mirisi utiču na njih u datom trenutku. Neki ispitanici možda nisu dovoljno senzibilni da razlikuju određene arome ili možda nisu osjetili različite mirise u prodajnom objektu da bi mogli jasno odrediti koja im aroma najviše odgovara.



Grafikon 7. Pobuđena osjećanja u odnosu na rasvjetu prodajnog objekta.
Graph 7. Aroused feelings in relation to the lighting of the sales facility.

Analizirajući podatke iz grafikona 31 najveći procenat ispitanika 51% percipira rasvjetu prodajnih objekata kompanije Kraš kao svečanu, a 25.5% ispitanika kao umirujuću. Ova dva osjećaja dominiraju, ukazujući na to da je rasvjeta uspješno osmišljena da stvori atmosferu koja je istovremeno elegantna i relaksirajuća. Manji procenat ispitanika 11.8% povezuje rasvjetu sa osećajem topline, dok 7.8% osjeća aktivnost, a samo 3.9% doživljava rasvjetu kao razdraganu. Nijedan ispitanik nije doživio rasvjetu kao hladnu, što dodatno potvrđuje pozitivan utisak koji rasvjeta ostavlja.

ZAKLJUČCI

Strateški osmišljen uslužni ambijent ima presudnu ulogu u stvaranju konkurentske prednosti kompanije, jer omogućava kompanijama da stvore jedinstveno korisničko iskustvo koje može diferencirati brend u odnosu na konkurenciju. Važnost uslužnog ambijenta ogleda se u sposobnosti da utiče na doživljaj potrošača i kroz emotivnu vezu sa brendom poveća njihovu lojalnost. Uslužni

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ambijent predstavlja ključan alat za diferencijaciju i prepoznatljivost, omogućavajući kompaniji da se izdvaja u odnosu na konkurenciju. Pravilno odabrane boje, osvjetljenje i muzika pružaju stvaranje jedinstvene atmosfere koja utiče na percepciju brenda kao prepoznatljivog i visokokvalitetnog. Korišćenje akcentnog osvjetljenja može naglasiti određene proizvode i učiniti ih privlačnijim, dok harmonična kombinacija boja stvara ugodan vizuelni doživljaj. Vizuelni stimulansi mogu značajno doprinijeti doživljaju potrošača i načinu na koji oni percipiraju brend. Taktilni stimulansi, poput teksture ambalaže ili dizajna prostora, dodatno osnažuju osjećaj kvaliteta i ekskluzivnosti, što utiče na pozitivan stav potrošača prema brendu i proizvodima. Na ovaj način, diferencirani uslužni ambijent omogućava kompaniji da izgradi jasan identitet koji će potrošači prepoznati i vrijednovati. Akcentno osvjetljenje, u kombinaciji sa taktilnim elementima poput dizajna ambalaže i tekstura, stvara sofisticiraniju i privlačniju percepciju proizvoda, što doprinosi njihovoj vrijednosti u očima potrošača. Kompanija Kraš, kroz pažljivo osmišljene elemente uslužnog ambijenta, uspijeva da izgradi prepoznatljiv brend i poveća lojalnost potrošača, čime direktno utiče na konkurentsku prednost. Rezultati empirijskog istraživanja pokazali su da strateško upravljanje uslužnim ambijentom kompanije Kraš ne samo da povećava zadovoljstvo potrošača, već im omogućava da brend povežu sa kvalitetom, inovativnošću i tradicijom, doprinoseći dugoročnoj lojalnosti i boljem poslovanju same kompanije. Kompanija Kraš treba da nastavi sa kontinuiranim unapređenjem uslužnog ambijenta, kako bi dodatno ojačala svoju poziciju i prilagodila se promjenjivim potrebama tržišta, ali i osigurala stečenu konkurentsku prednost u dinamičnom poslovnom okruženju.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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THE STRATEGIC ROLE OF THE SERVICE ENVIRONMENT IN THE PROCESS OF ACHIEVING A COMPETITIVE ADVANTAGE ON EXAMPLE OF THE KRAS COMPANY

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ABSTRACT

In today's business environment, where traditional methods of differentiation are becoming less effective, strategic management of the service environment is becoming crucial for maintaining a competitive advantage. Through a strategically designed service environment, companies can directly influence the shaping of consumer perception by creating a positive experience that reflects on the overall brand. Understanding and strategically applying the elements of the service environment allows companies to clearly differentiate themselves in the market by enhancing the customer experience and strengthening the emotional connection with consumers. This approach enables businesses to transform everyday interactions into key points of loyalty and trust, thereby not only strengthening brand reputation, but also ensuring its long-term sustainability in the market. The research goal of this paper is an analysis of the impact of the service environment on brand perception and consumer satisfaction, as well as how the strategic application of its elements can contribute to strengthening the competitive advantage and long-term business success of the company Kraš. The scientific-research character of this work is based on the analysis of relevant scientific literature and modern sources using the methods of analysis, comparison, examination, description and deduction. The results of the empirical research showed that a strategically designed service environment significantly contributes to the realization of the competitive advantage of the company Kraš, influencing the increase in user satisfaction, brand recognition and overall business performance.

Keywords: strategic management, service environment, Kraš.

ULOGA EMOTIVNE PISMENOSTI U SAVREMENOM MENADŽMENTU

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SAŽETAK

Izazovi dinamičnog globalnog tržišta, čiji efekti se odražavaju na uspješno poslovanje, nameću potrebu da se svaka organizacija intenzivnije bavi upravljanjem emocijama zaposlenih kako bi postale i ostale konkurentne. Zbog toga sve više organizacija posvećuje veliku pažnju razvoju emotivne pismenosti ljudskih resursa, jer predstavlja veoma uticajan faktor kada su u pitanju organizacione performanse, upravljanje promjenama, radni učinak, pregovaranje, motivacija, kreativnost, upravljanje konfliktima i liderstvo. Cilj istraživanja ovog rada predstavlja analiza uloge emotivne pismenosti u savremenom menadžmentu i uticaja koji ima na ostvarivanje poslovne izvrsnosti. Naučno-istraživački karakter ovog rada počiva na analizi relevantne naučne literature i savremenih izvora korišćenjem metoda ispitivanja, analize, deskripcije i dedukcije. Rezultati empirijskog istraživanja pokazali su da emotivna pismenost ima ključnu ulogu u izgradnji efikasnog emotivnog menadžmenta i odgovornog organizacionog ponašanja, koji direktno utiču na ostvarivanje konkurentne prednosti i poslovne izvrsnosti organizacije.

Ključne reči: emotivna pismenost, organizaciono ponašanje, menadžment

UVOD

Globalni trendovi nametnuli su savremenom menadžmentu da u fokus stavi ljudski kapital, ukoliko želi da ostvari i zadrži konkurentsku prednost. Konkurentska prednost je ključna za opstanak kompanija, pa je zbog toga potrebno pronaći prave ljude sa kreativnim idejama i iskoristiti ih za kreiranje superiorne vrijednosti. To znači poznavati ljudsku prirodu koja je satkana od emocija. Emocije su složen fenomen, čija univerzalna definicija ne postoji. Ipak, mogu se posmatrati kao uzbuđena stanja organizma izazvana spoljnim ili unutrašnjim doživljajima koja se manifestuju u obliku subjektivnog emotivnog doživljaja, ponašanja i fizioloških promjena u organizmu (Hyde, & Grieve, 2018). Postale su fokus istraživanja onoga momenta kada je i uloga ljudskih resursa u ostvarivanju poslovnog uspjeha postala neosporna činjenica. Emotivna pismenost predstavlja osnovu za izgradnju efikasnih emocija, koje imaju ulogu u poboljšanju poslovnih i organizacionih performansi (Popescu, Tascu, & Coconoiu, 2016). Emotivna pismenost se odnosi na pojedinačne razlike u prepoznavanju, razumijevanju, izražavanju, regulaciji i korišćenju vlastitih emocija i emocija drugih ljudi (Nelis, et al., 2011). Emotivno pismeni ljudi odlično poznaju sopstvene vrijednosti i mane, dobro procjenjuju ljude, umeju da kažu „ne“, posjeduju empatiju, svestrani su, umiju da opišu svoje emocije, ne potiskuju ih i razumiju. Oni znaju ko i šta na njih pozitivno ili negativno utiče, umiju da upravljaju svojim sposobnostima, spriječe vlastite mane da ih onemoguće u ostvarivanju ciljeva, razumiju druge i njihove potrebe.

Postoje dva osnovna modela emotivne pismenosti: modeli mentalnih sposobnosti i mješoviti modeli (Tafamel, & Ejechi, 2022). Modeli mentalnih sposobnosti podrazumijevaju sposobnost pojedinca da upravlja i organizuje svoje emocije i razmišlja o njima, a najvažniji predstavnici ovog trenda su Mayer i Salovey, koji su prvi identifikovali osnovne dimenzije emotivne pismenosti: percepciju emocija, emotivnu facilitaciju mišljenja, razumijevanje emocija i refleksivnu regulaciju emocija (Salovey, & Mayer, 1990). Sa druge strane, mješoviti modeli predstavljaju kombinaciju ličnih kvaliteta i emocija u njihovom društvenom kontekstu, kroz društvenu aktivnost i interakciju

sa drugima. Najvažniji predstavnik ovog trenda je Goleman, koji je definisao sljedeće dimenzije emotivne pismenosti: samosvijest, upravljanje emocijama, samomotivacija, empatija i društvene vještine (Goleman, 2001). Samosvijest označava sposobnost pojedinca da razumije svoja osjećanja i kontroliše svoje odgovore i reakcije (Makkar, & Basu, 2019). Upravljanje emocijama se definiše kao sposobnost pojedinca da se nosi sa negativnim problemima koji mogu imati negativan uticaj na njegov profesionalni i javni život, kao i njegov nivo učinka (Luthans, 2002). Empatija ukazuje na sposobnost pojedinca da sagleda i prihvati emotivna stanja, mišljenja i ponašanja drugih ljudi (Saarni, 2000). Socijalne vještine predstavljaju sposobnost pojedinca da razumije i pravilno reaguje na društvene situacije, dok istovremeno formira pozitivne odnose sa drugim ljudima ostvarujući profesionalne i lične ciljeve (Kassem, & Ahmed, 2021).

Emotivna pismenost je postala važna vještina, koja je ljudima potrebna da bi sarađivali, poboljšali svoje komunikacijske vještine i povećali svoje sposobnosti (Suchitra, & Sasmita, 2021). Takođe, smatra se važnim konceptom u savremenom poslovanju, jer predstavlja uticajan faktor u različitim administrativnim temama, kao što su organizacione performanse, radni učinak, pregovaranje, upravljanje konfliktima i liderstvo (Zehier et al., 2019). U tom smislu, predmet istraživanja jeste sagledavanje uticaja emotivne pismenosti na ponašanje i performanse zaposlenih. Cilj istraživanja ovog rada predstavlja analiza uloge emotivne pismenosti u savremenom menadžmentu i uticaja koji ima na ostvarivanje poslovne izvrsnosti. Na osnovu predmeta i cilja istraživanja, postavljena je generalna hipoteza:

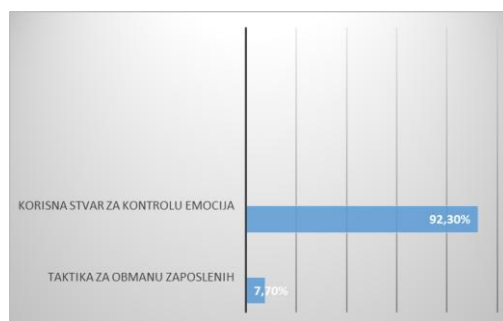
H1: Emotivna pismenost ima ključnu ulogu u izgradnji efikasnog emotivnog menadžmenta i odgovornog organizacionog ponašanja, koji direktno utiču na ostvarivanje konkurentске prednosti i poslovne izvrsnosti organizacije.

MATERIJAL I METODE RADA

Naučno-istraživački karakter ovog rada počiva na analizi relevantne naučne literature i savremenih izvora korišćenjem metode ispitivanja, metode analize, metode komparacije, metode deskripcije i metode dedukcije. Svrha istraživanja jeste da se više produbi razumijevanje načina na koji emotivna pismenost omogućava bolje poslovne performanse preduzeća i ostvarivanje konkurentnosti. Kao glavna metoda za prikupljanje podataka korišćena je metoda ispitivanja, a kao instrument anketa. Anketiranje je vršeno online putem na dva uzorka ispitivanja na teritoriji Republike Srpske. Prvi uzorak istraživanja sastojao se od 104 ispitanika koji nisu zaposleni na rukovodećim pozicijama, a drugi uzorak istraživanja je obuhvatao 100 ispitanika koji su na rukovodećim pozicijama u preduzećima na teritoriji Republike Srpske. Anketiranje je sprovedeno u mjesecu januaru 2025. godine.

REZULTATI I DISKUSIJA

Prvi uzorak istraživanja obuhvatio je zaposlene koji nisu na rukovodećim pozicijama, od čega je 58% ispitanika muškog pola, a 42% ispitanika ženskog pola. Najveći procenat ispitanika 48% je starosti između 41 i 50 godina. Kada je u pitanju stručna sprema i radno iskustvo, najveći procenat ispitanika 74,2% ima srednju stručnu spremu, a 84,1% imaju radno iskustvo duže od 10 godina.



Grafikon 1. Shvatanje emotivne pismenosti zaposlenih koji nisu na rukovodećim pozicijama.
Graph 1. Understanding emotional literacy of employees who are not in managerial positions.

Posmatrajući podatke iz grafikona 1 može se uočiti da najveći procenat ispitanika 92,3% smatra da je emotivna pismenost korisna stvar za kontrolu emocija, dok samo 7,7% ispitanika smatra da je emotivna pismenost taktika za obmanu zaposlenih. Ovaj podatak pokazuje da zaposleni vide emotivnu pismenosti kao pozitivan kontekst.

Tabela 1. Uticaj emotivne pismenosti na poslovno okruženje.

Table 1. The impact of emotional literacy on the business environment.

SKALACIJA	u potpunosti se ne slažem	ne slažem se	nemam mišljenje	slažem se	u potpunosti se slažem
Emotivna pismenost je važna komponenta za zdravo i efikasno poslovno okruženje	1%	6,3%	9%	41,5%	42,2%
Emotivna pismenost dovodi do većeg učinka organizacije	2,2%	4%	13,8%	47,8%	37,2%
Poslovna klima zavisi od emotivne pismenosti zaposlenih	1,7%	2,3%	20%	35%	41%
Veće vještine emotivne pismenosti omogućavaju lakše nošenje sa neuspjehom	1,3%	1,5%	15,4%	28,8%	53%
Emotivna pismenost olakšava pojedincu, ali ne i cijeloj kompaniji	20,6%	31,5%	39%	5,2%	3,7%

Podaci iz tabele 1 odnose se na stavove zaposlenih o uticaju emotivne pismenosti na poslovno okruženje. Najveći procenat ispitanika se slaže ili u potpunosti slaže da emotivna pismenost dovodi do većeg učinka organizacije 85% i da je emotivna pismenost važna komponenta za zdravo i efikasno poslovno okruženje 83,7%. Takođe, najveći procenat ispitanika se ne slaže ili u potpunosti ne slaže da emotivna pismenost olakšava pojedincu, ali ne i cijeloj kompaniji 51,1%. Ovi podaci pokazuju da zaposleni shvataju značaj i uticaj koji emotivna pismenost ima u savremenom poslovanju.

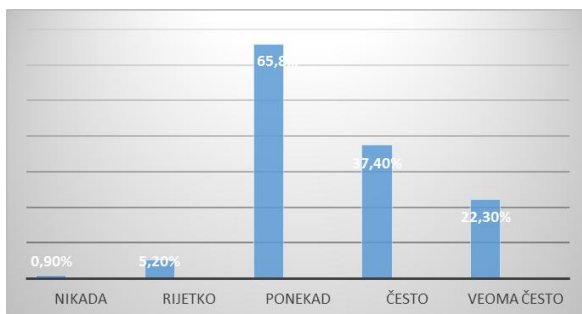
Tabela 2. Emotivna pismenost zaposlenih.

Table 2. Emotional literacy of employees.

SKALACIJA	u potpunosti se ne slažem	ne slažem se	nemam mišljenje	slažem se	u potpunosti se slažem
Smatram se emotivno pismenom osobom.	5,9%	9,8%	31,1%	29,4%	23,8%
Znam se nositi sa neuspjehom.	3,2	6%	35,2%	26,1%	29,5%
Ne dozvoljavam da me ometaju nesuglasice u kolektivu.	6,3%	18,2%	34,6%	32,5%	8,4%
Prihvatam konstruktivne kritike na miran način.	7,1%	17,6%	30,5%	23,6%	21,2%
Aktivno slušam prijedloge i želje kolega, iako mislim suprotno.	2,2%	8,1%	26,4%	31,8%	31,5%

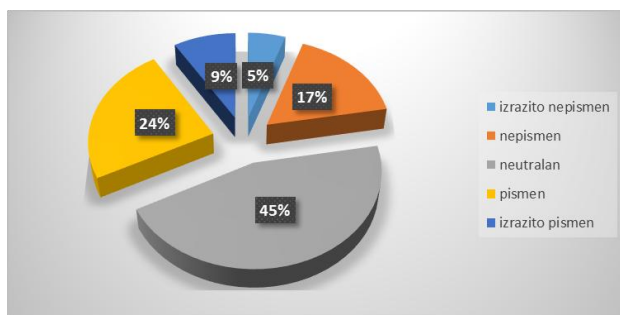
Podaci iz tabele 2 se odnose na emotivnu pismenost zaposlenih. Najveći procenat ispitanika se slaže ili u potpunosti slaže da aktivno slušaju prijedloge i želje kolega, iako misle suprotno 63,3%, znaju da se nose sa neuspjehom 55,6% i emotivno su pismeni 53,2%. Sa druge strane, najveći procenat ispitanika se ne slaže ili u potpunosti ne slaže da prihvataju konstruktivne kritike na miran način 24,7% i ne dozvoljavaju da ih ometaju nesuglasice u kolektivu 24,5%. Takođe, ne treba zanemariti ni činjenicu da se veći procenat ispitanika izjasnilo neutralno po pitanju skoro svih tvrdnji. Imajući u vidu prethodno navedeno može se zaključiti da zaposleni ne posjeduju sposobnost objektivnog samoocjenjivanja i ne razumeju u potpunosti koncept emotivne pismenosti, iako su svjesni njenog značaja za organizaciju. Zbog toga je neophodna da sve

kompanije pokrenu intenzivniju edukaciju o emotivnoj pismenosti i emotivnoj inteligenciji, kako bi zaposleni napredovali u profesionalnom i ličnom razvoju.



Grafikon 2. Učestalost sukobljavanja sa kolegama.
Graph 2. Frequency of conflicts with colleagues.

Analizirajući podatke iz grafikona 2 uočava se da najveći procenat ispitanika 65,8% ponekad ulazi u sukob sa kolegama, dok nešto manji procenat ispitanika 37,4% to čini često. Nažalost, najmanji procenat ispitanika ulazi u sukob nikad 0,9% ili rijetko 5,2%. Ovi podaci dodatno potvrđuju nizak nivo emotivne pismenosti i interpersonalnih vještina.



Grafikon 3. Ocjenjivanje emotivne pismenosti kolektiva.
Graph 3. Evaluation of collective emotional literacy.

Podaci iz grafikona 3 pokazuju da se najveći procenat ispitanika 45% izjasnio neutralno kada je u pitanju ocjena emotivne pismenosti kolektiva, dok se najmanji procenat ispitanika izjasnio da je kolektiv izrazito pismen 9% i izrazito nepismen 5%. Ovi podaci dodatno potvrđuju da zaposleni ne poznaju koncept emotivne pismenosti.

Drugi uzorak istraživanja obuhvatio je ispitanike koji su na rukovodećim pozicijama u preduzećima na teritoriji Republike Srpske, od čega je 55% ispitanika muškog pola, a 45% ispitanika ženskog pola. Najveći procenat ispitanika 45% je starosti između 41 i 50 godina. Kada je u pitanju stručna sprema i radno iskustvo, najveći procenat ispitanika 47% ima visoku stručnu spremu i radno iskustvo duže od 10 godina.

Tabela 3. Izražavanje i imenovanje emocija ispitanika koji su na rukovodećim pozicijama.

Table 3. Expression and naming of emotions of respondents who are in management positions.

SKALACIJA	u potpunosti se ne slažem	ne slažem se	nemam mišljenje	slažem se	u potpunosti se slažem
Mogu lako opisati svoje osjećaje	25%	45%	16%	11%	3%
Znam kako se zovu skoro svi moji osjećaji.	2%	7%	28%	51%	12%
Mogu dobro pokazati svoje osjećaje.	53%	9%	3%	33%	2%
Mogu prepoznati većinu svojih osjećaja.	7%	8%	24%	43%	18%

Podaci iz tabele 3 se odnose na izražavanje i imenovanje emocija ispitanika koji su na rukovodećim pozicijama. Najveći procenat ispitanika se slaže ili u potpunosti slaže da znaju kako se zovu skoro svi njihovi osjećaji 63% i da mogu prepoznati većinu svojih osjećaja 61%. Sa druge strane, najveći procenat ispitanika se ne slaže ili u potpunosti ne slaže da mogu lako opisati svoje osjećaje 70% i da mogu dobro pokazati svoje osjećaje 62%. Imajući u vidu prethodno navedeno, može se zaključiti da ispitanici na rukovodećim pozicijama imaju problem sa pokazivanjem emocija. Razlog za ovakvo ponašanje može se naći u samoj kulturi odrastanja na Balkanu, gde je fokus uglavnom bio na potiskivanju emocija, posebno u radnom okruženju, kako bi se izbjegao epitet „slabića“. Zbog toga je neophodno intenzivno edukovati mlade rukovodeće kadrove, pre svega tokom procesa školovanja, kako bi se na vreme spriječio štetan uticaj postojećih predrasuda.

Tabela 4. Uočavanje i razumevanje emocija ispitanika koji su na rukovodećim pozicijama.

Table 4. Observing and understanding the emotions of respondents who are in management positions.

SKALACIJA	u potpunosti se ne slažem	ne slažem se	nemam mišljenje	slažem se	u potpunosti se slažem
Mogu vidjeti kada je nekom krivozbog nečega.	2%	14%	3%	55%	26%
Primijetim kada se neko pravi da nije loše raspoložen.	7%	15%	39%	35%	4%
Primijetim kada neko skriva svoje prave osjećaje.	3%	57%	1%	26%	13%
Mogu vidjeti kada se neko ponaša drugačije od onoga kako je raspoložen.	57%	13%	1%	26%	3%
Primjetim kada se neko osjeća bespomoćno.	10%	17%	4%	8%	61%

Podaci iz tabele 4 se odnose na uočavanje i razumevanje emocija ispitanika koji su na rukovodećim pozicijama. Najveći procenat ispitanika se slaže ili u potpunosti slaže da mogu vidjeti kada je nekom krivo zbog nečega 81% i primjetiti kada se neko osjeća bespomoćno 69%. Sa druge strane, najveći procenat ispitanika se ne slaže ili u potpunosti ne slaže da mogu vidjeti kada se neko ponaša drugačije od onoga kako je raspoložen 70% i primjetiti kada neko skriva svoje prave osjećaje 60%. Imajući u vidu prethodno navedeno, može se zaključiti da ispitanici na rukovodećim pozicijama imaju razvijenu empatiju, što je veoma važno za adekvatno upravljanje ljudskim resursima. Ipak, njihova nesposobnost da sagledaju emocije koje nisu očigledne, može ozbiljno ugroziti poslovanje preduzeća i ostvarivanje poslovnih rezultata.

Tabela 5. Regulacija i upravljanje emocijama ispitanika koji su na rukovodećim pozicijama.

Table 5. Regulation and management of emotions of respondents who are in management positions.

SKALACIJA	u potpunosti se ne slažem	ne slažem se	nemam mišljenje	slažem se	u potpunosti se slažem
Mogu ostati dobro raspoložen/a i ako mi se nešto loše dogodi.	42%	10%	6%	40%	2%
I kada su svi oko mene loše raspoloženi, ja mogu ostati dobro raspoložen/a.	54%	11%	4%	4%	27%
Kada sam dobro raspoložen/a, teško me je oneraspoložiti.	3%	26%	14%	55%	2%
Kada sam dobro raspoložen/a, čini mi se da sve mogu lako riješiti.	4%	11%	4%	54%	27%
Riješiću i nešto jako teško iz inata.	18%	7%	4%	62%	9%

Podaci iz tabele 5 se odnose na regulaciju i upravljanje emocijama ispitanika koji su na rukovodećim pozicijama. Najveći procenat ispitanika se slaže ili u potpunosti slaže kako im se čini da sve mogu lako riješiti kada su dobro raspoloženi 81%, kao i da će riješiti i nešto jako teško iz inata 71%. Sa druge strane, najveći procenat ispitanika se ne slaže ili u potpunosti ne slaže da mogu ostati dobro raspoloženi i kada su svi oko njih loše raspoloženi 65%, kao i da mogu ostati dobro raspoloženi i ako im se nešto loše dogodi 52%. Imajući u vidu prethodno navedeno, može se zaključiti da su ispitanici koji su na rukovodećim pozicijama skloni fenomenu koji se naziva emotivna zaraza, posebno kada su u pitanju negativne emocije, dok pozitivne emocije vide kao pokretače unutrašnje snage da se lakše nose sa teškim situacijama. Ovi podaci su i paradoks, s obzirom da se najveći procenat ispitanika prethodno izjasnio da nije sposoban da pokaže svoje emocije.

Tabela 6. Emotivna samoeфикаsnost ispitanika koji su na rukovodećim pozicijama.
Table 6. Emotional self-efficacy of respondents who hold managerial positions.

SKALACIJA	u potpunosti se ne slažem	ne slažem se	nemam mišljenje	slažem se	u potpunosti se slažem
Lako mi je samog sebe razveseliti kad mi se dogodi nešto neugodno.	15%	39%	7%	35%	4%
Lako mogu sam sebe smiriti kada sam jako uplašen.	40%	6%	10%	40%	2%
Uspijevam se kontrolisati da ne postanem nervozan.	27%	29%	17%	7%	20%
Mogu lako kontrolisati svoja osjećanja.	36%	13%	8%	11%	32%
Mogu sam sebe ohrabriti kada se osjećam tužno.	7%	3%	14%	41%	35%
Nije mi teško reći prijatelju da se osjećam loše.	10%	19%	9%	52%	10%
Lako mi je potisnuti neugodne misli.	23%	5%	2%	6%	64%
Ne brinem se o onome šta bi se moglo dogoditi.	29%	28%	5%	16%	22%

Podaci iz tabele 6 se odnose na emotivnu samoeфикаsnost ispitanika koji su na rukovodećim pozicijama. Najveći procenat ispitanika se slaže ili u potpunosti slaže da mogu sami sebe da ohrabre kada se osjećaju tužno 76%, lako potisnu neugodne misli 70% i da im nije teško reći prijatelju da se osjećaju loše 62%. Sa druge strane, najveći procenat ispitanika se ne slaže ili u potpunosti ne slaže da ne brinu o tome šta bi se moglo dogoditi 57%, uspijevaju da se kontrolišu da ne postanu nervozni 56% i da lako mogu sebe da razvesele kada im se dogodi nešto neugodno 54%. Imajući u vidu prethodno navedeno, može se zaključiti da ispitanici koji su na rukovodećim pozicijama imaju razvijenu djelimičnu emotivnu samoeфикаsnost.

Podaci iz tabele 7 se odnose na uticaj emotivne pismenosti na poslovne performanse sa aspekta ispitanika koji su na rukovodećim pozicijama. Najveći procenat ispitanika se slaže ili u potpunosti slaže da emotivno pismeni zaposleni doprinose boljem poslovnom komuniciranju u radnom okruženju i bržoj razmjeni informacija 76%, kao i da emotivno pismeni zaposleni brže i bolje postižu rezultate u poslovnim pregovorima 67%. Sa druge strane, najveći procenat ispitanika se ne slaže ili u potpunosti ne slaže da emotivno pismeni zaposleni manipulacijom dolaze do boljih poslovnih rezultata 79%, kao i da emotivno nepismeni zaposleni stvaraju konfliktno okruženje 51%. Imajući u vidu prethodno navedeno, može se zaključiti da ispitanici koji su na rukovodećim pozicijama shvataju značaj i ulogu koje emotivna pismenost ima u savremenom poslovanju, kao i benefite koje donosi, ali još uvijek nisu u potpunosti savladali sve njene aspekte. Konstantna edukacija o emotivnoj pismenosti i koncepti tim bildinga koji je razvijaju i usavršavaju, mogu omogućiti ispitanicima koji su na rukovodećim pozicijama da poboljšaju svoje poslovanje i uživaju u svim benefitima koje donosi.

Tabela 7. Uticaj emotivne pismenosti na poslovne performanse sa aspekta ispitanika koji su na rukovodećim pozicijama.

Table 7. The impact of emotional literacy on business performance from the perspective of respondents who hold managerial positions.

SKALACIJA	u potpunosti se ne slažem	ne slažem se	nemam mišljenje	slažem se	u potpunosti se slažem
Emotivno pismeni zaposleni imaju bolji radni učinak	7%	20%	17%	27%	29%
Emotivno pismeni zaposleni doprinose boljem poslovnom komuniciranju u radnom okruženju i bržoj razmjeni informacija	1%	6%	17%	31%	45%
Emotivno nepismeni zaposleni stvaraju konfliktno okruženje	29%	22%	28%	16%	5%
Emotivno pismeni zaposleni brže i bolje postižu rezultate u poslovnim pregovorima	1%	5%	29%	53%	14%
Emotivno pismeni zaposleni manipulacijom dolaze do boljih poslovnih rezultata	58%	21%	19%	2%	0%

ZAKLJUČCI

Zahtjevno globalno tržište nameće organizacijama potrebu da se konstantno unapređuju, oslanjajući se na visokokvalifikovane ljudske resurse, koji trebaju da imaju visok stepen emotivne pismenosti kako bi što efikasnije i efektivnije ostvarili ciljeve organizacije i odgovorili na sve izazove u okruženju. Emotivna pismenost je povezana sa učinkom različitih organizacija, jer performanse u njima zavise od sposobnosti pojedinaca da uspješno komuniciraju sa drugima i od njihove sposobnosti da se suoče sa nepovoljnim ponašanjima, kontrolišu svoje emocije, motivišu druge i stvaraju pozitivne odnose sa njima. Rezultati empirijskog istraživanja pokazali su da emotivna pismenost ima ključnu ulogu u izgradnji efikasnog emotivnog menadžmenta i odgovornog organizacionog ponašanja, koji direktno utiču na ostvarivanje konkurentске prednosti i poslovne izvrsnosti organizacije. Zbog toga je neophodno obučiti lidere i pojedince koji rade u organizaciji da razvijaju i primjenjuju sve dimenzije emotivne pismenosti. Emotivna pismenost je ključ uspjeha poslovnih performansi u organizacijama, jer oni koji je posjeduju mogu da procjene situacije, predvide rezultate i shvate pozitivne i negativne aspekte koji mogu proizaći iz svake situacije, što se direktno odražava na uspjeh u poslovanju organizacije.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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THE ROLE OF EMOTIONAL LITERACY IN MODERN MANAGEMENT

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ABSTRACT

The challenges of the dynamic global market, whose effects are reflected in successful business, impose the need for every organization to deal more intensively with the management of employees' emotions in order to become and remain competitive. That is why more and more organizations are paying great attention to the development of emotional literacy of human resources, because it is a very influential factor when it comes to organizational performance, change management, work performance, negotiation, motivation, creativity, conflict management and leadership. The aim of this research is to analyse the role of emotional literacy in modern management and the impact it has on achieving business excellence. The scientific-research character of this work is based on the analysis of relevant scientific literature and contemporary sources using the methods of examination, analysis, description and deduction. The results of empirical research showed that emotional literacy plays a key role in building effective emotional management and responsible organizational behaviour, which directly affect the achievement of competitive advantage and business excellence of the organization.

Keywords: emotional literacy, organizational behavior, management.

ЕКОЛОШКЕ, ЕКОНОМСКЕ И ДРУШТВЕНЕ ДИМЕНЗИЈЕ ЦИРКУЛАРНИХ ПОСЛОВНИХ МОДЕЛА

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АПСТРАКТ

Потреба за новим пословним моделима заснованим на принципима одрживости и ефикасног коришћења ресурса у савременим економским условима постаје све очигледнија. Ови пословни модели теже отклањању основних слабости линеарног економског система, као што су неконтролисана експлоатација природних ресурса, стварање неповратног отпада, инхерентно слаба управљачка способност. Истовремено, они морају да задовоље све захтевније потребе тржишта, како на националном, тако и на глобалном нивоу.

У зависности од кључних карактеристика и циљева могуће је разликовати циркуларне пословне моделе засноване на: а) рециклажи и поновној употреби, б) дизајну за одрживост, в) услугама, г) процесима ланца снабдевања затворене петље, д) дигитализацији и ђ) образовно-консултантској природи. Истраживање сагледава еколошку, економску и социјалну димензију одрживости ових модела пословања. Закључује се да модели циркуларне економије засновани на рециклажи и ланцима снабдевања затворене петље најзначајније доприносе остваривању еколошких циљева, али могу деловати умерен и на економске димензије одрживости. С друге стране, модели оријентисани на услуге и дигитализацију доносе високе економске користи, уз умерен еколошки утицај.

Кључне речи: циркуларни пословни модели, ефикасност коришћења ресурса, загађење животне средине, принципи одрживости, димензије одрживости.

УВОД

Потреба за новим пословним моделима заснованим на принципима одрживости и ефикасног коришћења ресурса постаје све израженија у савременим економским условима. Нови модели производње теже превазилажењу кључних слабости линеарних концепата производње, укључујући неконтролисану екстракцију природних ресурса, неповратно генерисање отпада и ограничене управљачке капацитете. Истовремено, ови модели морају одговорити на све софистицираније захтеве тржишта, како на националном, тако и на глобалном нивоу (McKinsey, 2022).

У зависности од својих кључних карактеристика и стратешких циљева, савремени пословни модели у оквиру концепта циркуларне економије могу се класификовати на следеће категорије:

- модели засновани на рециклажи и поновној употреби,
- модели засновани на дизајну за одрживост,
- услужно оријентисани пословни модели,
- модели затвореног круга снабдевања,
- модели дигитализације и технологије,
- образовни и консултантски модели.

ЦИРКУЛАРНИ ПОСЛОВНИ МОДЕЛИ

Модели засновани на рециклажи и поновној употреби усмерени су ка продужењу животног циклуса производа и материјала, чиме се редукује количина отпада и минимизује експлоатација природних ресурса. Њихова основна претпоставка огледа се у трансформацији отпадних материјала у нове производе или у поновној употреби постојећих артикала, што доприноси очувању животне средине. Ови модели имају кључну улогу у унапређењу циркуларне економије јер умањују негативан утицај на природно окружење и афирмишу принципе одрживог развоја. У оквиру овог приступа, производи се дизајнирају тако да буду лако рециклабилни, док се паралелно развијају сервис базирани на дељењу, као и иницијативе за поправку и поновну употребу производа. Наведене праксе омогућавају предузећима да повећају тржишну конкурентност, остваре профит и истовремено поштују одрживе принципе (Bocken et al., 2016).

Модели дизајнирани за одрживост представљају иновативан приступ у обликовању производа и услуга, који у обзир узимају све аспекте животног циклуса – од набавке сировина, преко фазе производње и коришћења, до процеса рециклаже или поновне употребе. Темељни принципи екодизајна укључују смањење употребе материјала и енергије током целокупног процеса, продужење трајности производа, њихову једноставнију поправку и замену делова без потребе за одбацивањем целокупног производа, као и минимизацију отпада и емисија током производње. Такође, акценат се ставља на лакоћу демонтаже и рециклаже, што чини производе еколошки прихватљивијим.

Концепт циркуларне економије подразумева дизајнирање производа на начин који омогућава њихов продужен животни век, лакшу поправку, поновну употребу и рециклажу. Оваквим приступом значајно се смањује генерисање отпада и повећава ефикасност коришћења природних ресурса (Stahel, 2016). Директне последице ових модела укључују смањење потражње за сировинама, очување екосистема и биолошке разноврсности, као и реинтеграцију материјала у производне процесе, који би иначе завршили на депонијама (Ghisellini et al., 2016). Додатно, доприноси смањењу емисије угљен-диоксида, што представља један од кључних корака у борби против климатских промена. Овај приступ, осим што минимизује негативне еколошке утицаје производних активности, истовремено стимулише развој одрживих алтернатива, као што су употреба биоматеријала и рециклираних индустријских остатака, који додатно доприносе заштити животне средине.

Услужно оријентисани пословни модели представљају помак са традиционалног концепта власништва ка моделима заснованим на коришћењу и функционалности производа. Уместо продаје производа као крајњих добара, предузећа нуде приступ производима кроз услуге, као што су изнајмљивање, дељење, одржавање и поправке. Овај модел омогућава оптимизацију искоришћености ресурса, јер се производи користе ефикасније и током дужег временског периода, чиме се смањује потреба за њиховом масовном производњом и потрошњом (Tukker, 2015).

Кључне користи услужних модела огледају се у економској одрживости - кроз стабилне изворе прихода, лојалност потрошача и ниже трошкове производње. Са становишта животне средине, ефекти су умерени, али ипак позитивни, јер продужено коришћење производа смањује генерисање отпада и успорава циклус замене производа. Ови модели такође подстичу иновације у дизајну и одржавању производа, јер произвођачи остају одговорни за перформансе производа током целог његовог животног века.

Модели затвореног круга снабдевања фокусирани су на оптимизацију токова материјала кроз реинтеграцију отпадних производа, делова и сировина назад у производне системе. Суштина овог модела јесте затварање материјалних и енергетских токова кроз постојање реверзних логистичких процеса - укључујући сакупљање, селекцију, демонтажу и прераду искоришћених производа. Овај приступ омогућава значајне уштеде у потрошњи ресурса и енергије, као и смањење екстернализованих еколошких трошкова (Abdallah et al., 2024).

Одржива логистика, дигитално праћење производа, као и партнерства у ланцу снабдевања, кључни су фактори успешне имплементације овог модела. Еколошке користи

Andrejević Panić, A. i sar. (2025). Ekološke, ekonomske i društvene dimenzije cirkularnih poslovnih modela. *STED Conference 14(2)*, 129-134.

су изузетно високе, док се економски ефекти могу кретати у распону од умерених до значајних, у зависности од ефикасности система повратка и прераде ресурса. Овај модел нарочито је погодан за секторе у којима је могућа стандардизација компоненти и контрола животног циклуса производа.

Модели дигитализације и технологије обухватају употребу дигиталних алата — као што су интернет ствари, вештачка интелигенција, блокчејн, биг дата и платформе за дељење - ради унапређења одрживости пословања. Дигиталне технологије омогућавају прецизније управљање ресурсима, праћење употребе производа у реалном времену, оптимизацију токова материјала и омогућавање сервитизације. На пример, дигитални близанци омогућавају симулацију перформанси производа и предвиђање кварова, чиме се продужава њихов животни век и унапређује ефикасност (Pagoropoulos et al., 2017).

Економски потенцијал дигитализације је висок, будући да доприноси смањењу трошкова, побољшању оперативне ефикасности и развоју иновативних пословних модела. Еколошки доприноси су умерени и зависе од тога да ли се дигитална решења користе за подршку одрживим праксама или искључиво за повећање профита. Ипак, потенцијал дигитализације да омогући транспарентност и следљивост у целокупном ланцу вредности чини је кључним алатом за системску трансформацију ка циркуларним принципима.

Образовни и консултантски модели усмерени су на подизање свести, јачање капацитета и пренос знања неопходног за прелазак ка циркуларним праксама. Ови модели могу се реализовати кроз формалне образовне програме, корпоративне тренинге, саветодавне услуге и стручну подршку за дизајнирање и имплементацију циркуларних решења. Њихов значај огледа се у ширењу знања о одрживости, развоју нових вештина и стварању професионалних мрежа које убрзавају системске промене (Kirchherr et al., 2018).

Иако немају директан физички утицај на токове ресурса, ови модели индиректно доприносе еколошкој и економској одрживости кроз оснаживање актера за промену пословне праксе. Њихова улога постаје нарочито важна у контексту транзиције малих и средњих предузећа, која често немају капацитете за самосталан развој одрживих стратегија.

КОМПАРАЦИЈА ЕКОЛОШКИХ, ЕКОНОМСКИХ И ДРУШТВЕНИХ УТИЦАЈА ПОЈЕДИХ ЦИРКУЛАРНИХ ПОСЛОВНИХ МОДЕЛА

У табели 1 презентован је компаративни преглед еколошких, економских и друштвених утицаја различитих циркуларних пословних модела на концепт одрживости. Преглед може служити као користан алат у процесу одабир стратегија развоја ЦЕ.

Табела 1. Еколошки, економски и друштвени утицаји шест пословних модела релевантних за циркуларну економију.

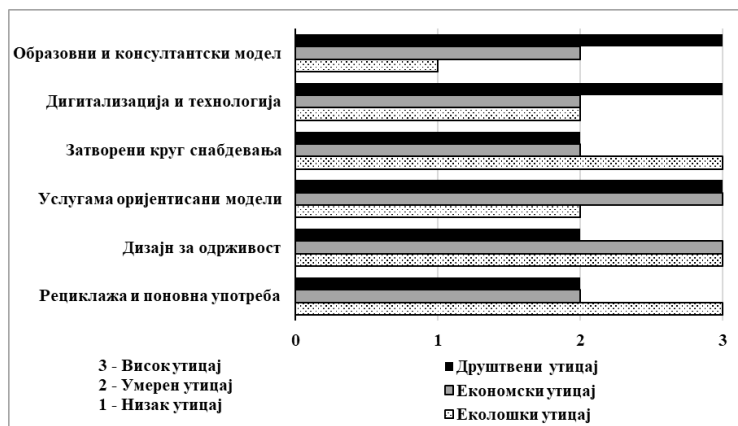
Table 1. Environmental, economic and social impacts of six business models relevant to the circular economy.

Група пословних модела	Еколошки утицај	Економски утицај	Друштвени утицај
Рециклажа и поновна употреба	Висок Смањење отпада, очување природних ресурса.	Умерен Почетни трошкови рециклаже су високи, али дугорочно обезбеђују уштеду.	Умерен Допринос повећању свести потрошача о значају одрживости.
Дизајн за одрживост	Висок Продужење животног века производа, мањи еколошки утицај.	Висок Остварује значајну дугорочну уштеду кроз смањене трошкове замене производа.	Умерен Едукација потрошача о важности одрживих производа.
Услугама оријентисани модели	Умерен Смањење отпада кроз дужу употребу производа.	Висок Обезбеђује стабилне приходе и пословну отпорност.	Висок Подстиче укључивање потрошача у одрживе праксе, као што су лизинг и изнајмљивање.

Затворени круг снабдевања	Висок Потпуна циркуларност коришћења материјала.	Умерен Улагања у логистичке системе су велика, али дугорочно снижавају трошкове сировина.	Умерен Доприноси друштвеној одговорности предузећа и подршци локалним заједницама кроз рециклажу.
Дигитализација и технологија	Умерен Омогућава оптимизацију коришћења ресурса, али дигитална инфраструктура има свој еколошки утицај.	Умерен Захтева велике иницијалне инвестиције, али доприноси побољшању продуктивности и управљања ресурсима.	Висок Олакшава интеракцију и транспарентност између компанија и потрошача.
Образовни и консултантски модел	Низак Индиректни еколошки утицај кроз едукацију и саветовање.	Умерен Консултантске услуге су исплативе у зависности од интересовања тржишта.	Висок Значајно доприносе подизању свести и преносу знања о циркуларној економији.

Напомена: утицаји су класификовани као висок, умерен и низак на основу њихове способности да генеришу позитивне промене.

Пословни модели попут рециклаже и затвореног круга снабдевања највише доприносе остварењу еколошких циљева, мада могу представљати умерене економске изазове. Са друге стране, услугама оријентисани модели и дигитализација доносе значајне економске користи уз умерени утицај на животну средину (Слика 1).



Слика 1. Графички приказ утицаја шест пословних модела релевантних за циркуларну економију.
Figure 1. Graphical representation of the impact of six business models relevant to the circular economy.

Систематизација ових група пословних модела може обухватити креирање матрица које повезују поједине моделе са њиховим предностима, изазовима и потенцијалима примене у различитим индустријама. Ово не само да доприноси бољем разумевању концепта ЦЕ, већ и подстиче њену практичну примену.

ЗАКЉУЧЦИ

ЦЕ представља важан елемент концепта одрживог развоја. Применом њених принципа, друштва могу постићи економски раст који није у супротности са заштитом животне средине и друштвеним благостањем, стварајући услове за рационално управљање ресурсима уз смањење негативних утицаја на природу. Следи природну логику кружног кретања,

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наглашавајући поновну употребу отпада, ефикасно коришћење енергије и оптимизацију односа између производње и потрошње. Овај модел омогућава да се ефекти потрошње враћају у производни процес, чиме се минимизирају губици ресурса и смањује загађење. ЦЕ тежи одрживости кроз рециклажу, поновну употребу и обнову материјала, супротстављајући се традиционалном „узми-направи-баци“ приступу.

Концепти као што су услуга уместо власништва и решења заснована на природи представљају темеље ЦЕ и одрживог развоја. Њихова примена не само да смањује потрошњу ресурса и негативне утицаје на животну средину, већ уводи и нове пословне modele који подстичу дугорочну одрживост. Уз све већу потребу за еколошки прихватљивим стратегијама, ови модели играју све значајнију улогу у преобликовању глобалне економије.

Циркуларна економија обухвата низ стратешких активности и пракси, које укључују: а) осмишљавање производа који су трајнији, лакши за поправку, поновну употребу и рециклажу, б) поновно коришћење материјала ради минимизације потребе за екстракцијом нових сировина, в) подстицање дуготрајне употребе производа кроз изнајмљивање, дељење и сервисирање, г) усмеравање енергетских система на коришћење обновљивих извора уместо фосилних горива.

Уз подршку адекватних политика, технолошких иновација и друштвених промена, циркуларна економија има потенцијал да значајно трансформише савремене привредне системе.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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ECOLOGICAL, ECONOMIC AND SOCIAL DIMENSIONS OF CIRCULAR BUSINESS MODELS

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ABSTRACT

The need for new business models based on the principles of sustainability and efficient resource use in modern economic conditions is becoming increasingly evident. These business models strive to eliminate the fundamental weaknesses of the linear economy, such as uncontrolled extraction of natural resources, irreversible waste generation, and their inherently weak management potential. At the same time, they must meet increasingly demanding market needs, both on a national and global level.

Depending on the key characteristics and goals of circular business models based on: a) recycling and reuse, b) design for sustainability, c) services, d) closed-loop supply chain processes, e) digitalization, and f) educational and consultancy nature, the study considers their impact on the ecological, economic, and social dimensions of sustainable business. It concludes that recycling and closed-loop supply chain circular business models most significantly advance ecological goals but may carry moderate economic challenges. On the other hand, service-oriented models and digitalization bring high economic benefits, with moderate ecological impact.

Keywords: circular business models, resource use efficiency, environmental pollution, sustainability principles, sustainability dimensions.

CO-AUDITING AS A TOOL FOR ASSESSING AND SHAPING LONG-TERM SUSTAINABLE BUSINESS STRATEGIES

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ABSTRACT

Intensive activity in operationalizing long-term sustainable business strategies and the increasing technological and commercial affirmation of many of its tools have enabled the emergence of eco-auditing as a process for assessing the environmental performance of organizations, products, or services with the aim of improving the environmental aspects of business. The comprehensiveness of eco-auditing refers to the thoroughness of the assessment, including analysis of environmental impact, compliance with legislation, and identification of opportunities for more sustainable practices.

The paper first reflects on the role of eco-auditing in organizations to:

- identify environmental risks,
- improve compliance with legislation and standards,
- enhance competitiveness, and
- build trust with consumers and partners by demonstrating responsibility toward the environment.

The emphasis of the paper then shifts to explaining the key standards of eco-auditing and providing practical examples where this tool serves as a foundation for sustainable business and environmental protection. Finally, focusing on the construction industry and companies using the Leadership in Energy and Environmental Design (LEED) standards for design and construction, organizations from Serbia and Bosnia and Herzegovina that have undertaken the LEED certification process are highlighted as tools to improve building energy efficiency and sustainability.

Keywords: environmental management, eco-auditing, LEED, energy efficiency, building sustainability.

INTRODUCTION

In today's business environment, where environmental protection and sustainable development have become global priorities, organizations are increasingly under pressure to reassess their environmental performance and contribution to both the community and the natural environment. Environmental management represents both the science and art of managing various levels of organizational systems by controlling environmental risks that threaten the survival of these systems. It is necessary to raise awareness about pollution, to assume responsibility, and to take steps toward stopping pollution—if not entirely, then to an acceptable or minimal level. Changes should begin within the organization itself by investing in development that primarily involves long-term and far-reaching changes in technology, which must become increasingly cleaner.

In this context, environmental auditing emerges as one of the key tools enabling a systematic assessment, monitoring, and improvement of the environmental aspects of business operations,

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products, and services. As a comprehensive process, environmental auditing not only identifies environmental weaknesses and risks but also provides organizations with a foundation for strategic decision-making toward sustainable development.

Environmental auditing, also known as ecological or green auditing, encompasses a range of activities including the analysis of an organization's environmental impact, verification of compliance with legal and regulatory frameworks, and the identification of areas where better and more efficient environmental practices can be applied. This type of audit is particularly significant because it does not solely focus on meeting formal requirements; it also has a broader goal—improving business operations through responsible resource management, reducing waste, emissions, and energy consumption, and promoting the principles of a circular economy.

ENVIRONMENTAL MANAGEMENT

Environmental management is a fully anthropocentric or human-centered concept of business management. It is not merely a standard science and skill of effective and efficient behavior and goal achievement in the right way, but rather a true knowledge and practice of attaining the right goals - those concerning human survival and the quality of human life. In no other area of management application is the dominance of the principle of effectiveness over the principle of efficiency confirmed so strongly and convincingly. In other words, the lack of effectiveness (i.e., poorly chosen, inhumane, and non-ecological goals) cannot be compensated for, even by the highest level of efficiency.

This has been supported by the introduction of international environmental management standards, such as the ISO 14000 series from 1994, followed later by the 18000 series and others. Their primary role is to provide unified guidelines for environmental policy; to define strategic and operational objectives; to identify and assess environmental impacts; to establish internal and external audit procedures; to set communication principles; and to define obligations for training, among other things.

In this sense, environmental management system standards represent a further elaboration and concretization of the well-known *Business Charter for Sustainable Development*, which was adopted in 1991 within the framework of the International Chamber of Commerce. At that time, it was proclaimed that environmental management must be a priority task for companies, that ecology must be integrated into company management, and that its improvement must be a continuous process. It was also emphasized that employees must be continuously motivated and educated on environmental matters; that constant assessment of the environmental impacts of every new process and product must be carried out; that the company must take responsibility for the conduct of its partners and suppliers; that the company must be open to dialogue on environmental risks and actively engaged in joint efforts to raise environmental awareness and regularly inform all interested parties (Pokrajac, 2001, 107).

ECO-AUDIT AS A TOOL OF ENVIRONMENTAL MANAGEMENT IN ORGANIZATIONS

The introduction of eco-auditing into business practices brings numerous benefits. Firstly, organizations can timely identify environmental risks that could threaten their operations or reputation. Secondly, eco-auditing increases compliance with domestic and international laws and standards, which facilitates easier access to foreign markets and partnerships. Thirdly, companies that actively conduct eco-audits often gain a competitive advantage, as consumers and investors are increasingly interested in sustainable and environmentally responsible products and services.

Eco-auditing is an important step toward building trust among consumers and the public. Transparent reporting on audit results, including improvement measures, sends a clear message that the company is committed to environmental protection and socially responsible business practices. In today's society, where environmental awareness is on the rise, such an approach can significantly influence an organization's image and market success.

In practice, implementing an eco-audit requires a multidisciplinary approach, involving experts from ecology, management, law, and technology, as well as the active participation of

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employees. The process typically includes several phases: planning, data collection and analysis, evaluation of results, report preparation, and proposals for improvement. A key aspect of a successful eco-audit is continuity - it must not be a one-time action but a continuous practice within the environmental management system.

For example, many companies seeking alignment with standards such as ISO 14001 or LEED use eco-auditing as a fundamental tool for assessing current conditions and defining action plans. This is especially true in industries with significant environmental impacts, such as construction, energy, or the chemical industry, where eco-auditing becomes essential for maintaining competitiveness and legal compliance.

In an era of global awareness about the importance of environmental protection, business organizations are facing increasing pressure to align their operations with the principles of sustainable development. One of the key tools enabling the systematic reassessment and improvement of environmental aspects of business is the eco-audit. Eco-auditing represents a process of assessing an organization's impact on the environment through the analysis of processes, products, and services, with the aim of achieving better performance in accordance with environmental and regulatory standards (Hilary, 1997).

The main roles of eco-auditing in modern organizations are: identifying environmental risks, improving compliance with laws and standards, enhancing competitiveness, and building trust among consumers and partners.

Eco-auditing enables organizations to identify and quantify potential environmental risks that may arise from their activities. These risks include water, soil, and air pollution, improper waste management, and inefficient resource consumption. Timely detection of such weaknesses through eco-auditing reduces the likelihood of environmental incidents and harmful consequences for local communities and the surrounding environment (Environmental Protection Agency [EPA], 2021). Organizations that conduct regular eco-audits gain clearer insight into the critical points of their operations and develop risk mitigation plans.

In an increasingly complex regulatory environment, compliance with laws and environmental standards is becoming more challenging. Eco-auditing helps organizations systematically monitor and document their compliance with applicable legislation and industry norms, including international standards such as ISO 14001. This practice not only reduces the risk of fines and legal consequences but also facilitates the continuous improvement of environmental performance through the implementation of audit-derived recommendations (International Organization for Standardization [ISO], 2015).

In today's market, sustainability is increasingly viewed as an advantage rather than merely an obligation. Companies that actively conduct eco-audits often achieve better market positioning by adopting environmentally efficient technologies, reducing operational costs through resource optimization, and gaining access to "green" funds and public tenders (Delmas & Toffel, 2008). Such organizations also tend to enjoy a stronger reputation, which directly contributes to their competitiveness.

Transparency and accountability are key values increasingly appreciated by consumers and business partners. When eco-audit results are communicated clearly and openly, they serve as a powerful indicator of social responsibility and environmental commitment. This helps build trust and loyalty among customers, investors, and partners, thereby creating a positive corporate image (Bansal & Roth, 2000). In a society that values sustainability, eco-auditing is not just a tool for internal evaluation but also a means of external positioning.

Eco-auditing is more than an administrative requirement - it is a strategic tool that enables organizations to evolve toward sustainability. Through risk identification, regulatory compliance, increased competitiveness, and trust-building, eco-auditing contributes to the long-term success of organizations and the preservation of natural resources. In the future, more and more companies will need to integrate eco-auditing into their everyday operations - not only due to regulatory obligations but also in response to consumer expectations and global societal demands.

KEY STANDARDS OF ECO-AUDITING

Eco-auditing is a key mechanism through which organizations systematically assess their environmental impact, identify opportunities for improvement, and direct their operations toward a more sustainable model. This tool is especially important in the context of growing global concerns about climate change, resource depletion, and ecosystem preservation. Eco-auditing is conducted in accordance with a range of internationally recognized standards that provide a framework for evaluating and enhancing environmental performance.

The key standards of eco-auditing include:

- ISO 14001 – Environmental Management Systems
- EMAS – EU Eco-Management and Audit Scheme
- LEED – Leadership in Energy and Environmental Design

The most significant global standard for eco-auditing is ISO 14001, which defines the requirements for an environmental management system. This standard helps organizations identify and manage the environmental aspects of their activities, ensure compliance with legal requirements, and continuously improve their environmental performance (ISO, 2015). Its core components include planning, implementation, checking, and acting (the Plan-Do-Check-Act cycle), which enables a dynamic and iterative approach to environmental protection.

EMAS is a European standard that combines the requirements of ISO 14001 with additional elements, such as public disclosure of environmental reports, stricter verification rules, and a stronger emphasis on transparency. This framework allows organizations to strengthen public and stakeholder trust through documented commitment to environmental preservation (European Commission, 2020).

Although not a classical eco-auditing standard, LEED is a widely applied framework for assessing building sustainability. Through a point-based system, LEED evaluates energy efficiency, indoor environmental quality, material use, waste management, and other factors that directly affect the environment. LEED certification often includes eco-audits as part of the preparation process (USGBC, 2021).

LEED is a rating system developed by the U.S. Green Building Council (USGBC) that evaluates the environmental efficiency and sustainability of buildings across various categories: energy efficiency, water usage, material selection, indoor environmental quality, transportation, innovation, and site location. Buildings can be certified at four levels - Certified, Silver, Gold, and Platinum - depending on the number of points earned.

LEED is not just a technical standard -it is a strategic tool that contributes to reduced operational costs, improved occupant health, lower carbon footprints, and increased market value of real estate.

CONSTRUCTION INDUSTRY AND LEED STANDARDS: EXAMPLES FROM SERBIA AND BOSNIA AND HERZEGOVINA

The construction industry has a significant impact on the environment, primarily through the consumption of natural resources, waste generation, emission of harmful gases, and influence on energy consumption. Given these challenges, it is crucial to implement tools that enable more sustainable design, construction, and building management. One of the most recognized international standards in this field is LEED, which sets criteria for "green building."

In Serbia, an increasing number of investors and designers are recognizing the importance of LEED standards as a way to improve construction quality and meet the growing expectations of the market, especially among international clients. One of the most well-known examples of LEED certification in Serbia is the Delta House office building, the headquarters of Delta Holding, which received a LEED Gold certificate. The building was designed to use energy-efficient HVAC systems, LED lighting, motion sensors, as well as rainwater collection and greywater recycling systems. Local and recycled construction materials were used, with special emphasis on indoor air quality and employee comfort (Delta Holding, 2022). Companies such as MPC Properties and AFI Europe have also implemented LEED certification for their office and shopping centers, such as

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Ušće Tower 2 and Skyline AFI Tower, to increase the buildings' energy efficiency and reduce operational costs (MPC Properties, 2023). In these cases, LEED has also served as a marketing tool, as tenants and users are increasingly seeking "green" business spaces.

Although the process is slower compared to Serbia, Bosnia and Herzegovina has seen its first successful examples of LEED standard application, particularly in large infrastructure and corporate projects. The Green Park project, a mixed-use residential and commercial complex in Sarajevo, applies LEED principles in its design and implementation - especially in terms of smart heating and cooling systems, insulation, low-emission facades, and water-saving technologies. Although the certification process has not been completed, the building was developed according to LEED criteria with the goal of future certification. The company Energopetrol, within its gas stations in Sarajevo and Mostar, has implemented sustainability elements aligned with LEED standards - such as solar panels, LED lighting, and wastewater recycling systems. Although they have not undergone full certification, these initiatives demonstrate the practical adoption of LEED principles (Green Building Council Bosnia and Herzegovina, 2022).

ADVANTAGES AND CHALLENGES OF LEED CERTIFICATION

Advantages:

- Energy Efficiency – Significant reduction in energy consumption, leading to lower operating costs.
- Occupant Health – Improved air quality and lighting positively affect productivity and overall well-being.
- Market Value – LEED-certified buildings attract higher-quality tenants and achieve higher rental and resale prices.
- Regulatory Compliance – Many LEED components align with environmental protection and energy efficiency regulations.

Challenges:

- High Initial Costs – Implementing sustainable technologies often requires greater upfront investment.
- Lack of Local Expertise – LEED certification requires specialized engineers, designers, and auditors, which may be scarce locally.
- Bureaucracy – The certification process involves extensive documentation and can take several months to complete.

CONCLUSION

Eco-auditing represents a fundamental mechanism for achieving long-term business sustainability. Its implementation helps organizations better understand their environmental responsibilities and potentials, respond to growing demands from the market and regulators, and actively contribute to global environmental protection goals. In an era where success is measured not only by profit but also by responsibility toward society and nature, eco-auditing is a step no serious organization should overlook.

When conducted in accordance with internationally recognized standards such as ISO 14001, EMAS, and LEED, eco-auditing serves as a powerful tool for improving sustainable business practices and environmental protection. By identifying environmental aspects, enhancing compliance, optimizing resource use, and strengthening public trust, eco-audits enable organizations to make their operations more environmentally responsible. Practical examples from the region confirm that eco-auditing is not merely a regulatory requirement, but a strategic instrument for long-term development and competitive advantage.

LEED standards are a powerful tool for transforming the construction industry toward sustainability. Companies from Serbia and Bosnia and Herzegovina that have adopted LEED principles have demonstrated that aligning business objectives with environmental protection principles is both feasible and beneficial. While challenges exist, the trend clearly indicates that the

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number of LEED-certified buildings in the region will continue to grow—especially with the support of government incentives and increasing environmental awareness among investors and building users. The implementation of LEED standards is not just “green” marketing, but a genuine step toward a sustainable and responsible construction sector.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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MOGUĆNOSTI I ASPEKTI INTEGRACIJA U JAVNOM ZDRAVSTVU

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SAŽETAK

Integracije zdravstvenih ustanova u javnom zdravstvu ilustruju proces koji nije dovoljno proveden, niti je organizacija mreže javnih zdravstvenih ustanova postavljena na principima funkcionalne integracije. Predstavljene su barijere između javnih zdravstvenih ustanova, a njihovo otklanjanje još ne ispunjava potrebe korisnika.

Zakonske odredbe predviđaju mogućnosti organizovanja u integrisane zdravstvene ustanove koje sadrže delove primarnog i sekundarnog nivoa zdravstvene zaštite. Međutim u Bosni i Hercegovini ne postoji niti jedna javna zdravstvena ustanova koja je organizovana prema ponuđenom zakonskom rešenju. Dupliranje medicinskih usluga je čest slučaj kod pacijenta koji prelazi iz jedne zdravstvene ustanove u drugu ustanovu, što predstavlja gubitak vremena i novca.

Predmet istraživanja čine javne zdravstvene ustanove primarnog i sekundarnog nivoa zdravstvene zaštite i način njihovog optimalnog organizovanja sa aspekta troškova i kvaliteta kroz integracije.

Problem istraživanja je primjena drugačijih načina organizovanja zdravstvene zaštite, ograničenih nedostatkom osoblja, opreme, novca i rastućim troškovima.

Rezultat istraživanja sadržan je u stavu da se drugačijim načinom organizovanja javnih zdravstvenih ustanova, može postići bolje korišćenje dostupnih resursa u ustanovama primarnog i sekundarnog nivoa zdravstvene zaštite. Kriterijumi za integraciju u zdravstvu mogu da sadrže ekonomske, funkcionalne, medicinske i organizacione aspekte, a njihovo provođenje zavisi i od volje donosilaca odluka o organizovanju zdravstva.

Ključne reči: zdravstvena ustanova, nivo zdravstvene zaštite, integracija zdravstvenih ustanova.

UVOD

Optimalno organizovanje javne zdravstvene zaštite zahteva multidisciplinarn pristup, ako se ima u vidu, da se istovremeno podmiruju potrebe i zahtjevi korisnika zdravstvenih usluga i društvene zajednice, koji teže maksimalnom zadovoljavanju sa aspekta troškova i kvaliteta medicinske usluge. Jedan od aspekata integrisanja zdravstvenih ustanova primarnog i sekundarnog nivoa zdravstva nalazi se u smanjenju troškova uz isti ili rastući kvalitet i obim medicinskih usluga. Optimalna struktura zdravstva postavlja se poštivanjem niza kriterijuma i principa organizovanja: ekonomičnost zaštite, efikasnost davalaca medicinskih usluga, dostupnost zdravstvenih ustanova, pokrivenost mrežom ustanova, kvalitet i cena usluge, troškovi liječenja i budžeti za zdravstvo, zadovoljstvo pacijenta, zdravstveni indikatori populacije, broj stanovnika na jednog lekara itd. Pojedini kriterijumi optimizacije su suprotstavljeni, te se pri planiranju postavlja pitanje nejednakog zadovoljavanja, imajući u cilju ekonomski optimum.

Izbor načina organizovanja mreže zdravstvenih ustanova nije problem koji će rešiti jednom odlukom, za sve subjekte i za sva vremena. Komparativna analiza sistema zdravstvene zaštite u evropskim zemljama, posebno zdravstvenog osiguranja kao jednog od ključnih elemenata tog sistema, pokazuje da se ona ne organizuje i ne sprovodi svuda na isti način, već da svaka od oko 200 država koliko ih danas ima na planeti, predviđa sopstvena pravila u toj oblasti. (Jovičić et al.,

2014, str. 5). Postojanje limitirajućih faktora, kao i specifičnosti sredine za koju se donose odluke, te snažna dinamika elemenata koji utiču na izbor rešenja problema, čine kompleksnost efikasnog organizovanja zdravstvene zaštite, uz neizostavno praćenje kvaliteta zdravstvene usluge. Okruženje u kojem deluje zdravstvena ustanova je promenljivo a pojedine promene nastaju velikom brzinom. U ovom radu, uži aspekt analize je fokus na rad javnih zdravstvenih ustanova. Kvalitet i brzina pružanja povezanih medicinskih usluga čine prednost jedne zdravstvene ustanove i način na koji će javna zdravstvena ustanova, sa širom paletom opreme i vrstom osoblja, ostvariti konkurentsku prednost u odnosu na privatne davaoce zdravstvenih usluga. Pozitivni su i prateći efekti, jer se istovremeno uvećavaju vlastiti prihodi, iskorišćeniji su medicinski kapaciteti i zadovoljniji pacijenti, uz ukupan viši kvalitet rada ustanove.

Međutim, svi institucionalni akteri zdravstvene djelatnosti nisu motivisani niti kooperativni u praćenju i sprovođenju promena, a otpori promenama nisu specifičnost samo zdravstvene djelatnosti, već su prisutni i u okruženju ustanove. Stoga je argumentiranje potrebe provođenja promjena i uvođenja novih organizacionih oblika, tokova i veza u zdravstvenom sistemu, definisanom i zakonskim odredbama, utoliko složeniji posao. Uvođenje novih tehnologija kao i svega koje postaje karakteristično za integrisanu zdravstvenu zaštitu, kao što su obuka, priprema i edukacija za rad u novom organizacionom obliku, postaju prateće manifestacije procesa integrisanja, ali i mesta o kojima će se voditi diskusija o neophodnosti promena.

Razloge otpora promenama treba analizirati i ne odbacivati unapred, naprotiv, oni su korisni kontraargumenti, dobrodošlo suprotno mišljenje, korektivna svest zbog kojih donosilac odluke treba obratiti pažnju na vreme, uslove, ograničenja i dinamiku odlučivanja o promenama

TEORIJSKI OKVIR

Organizovanje zdravstvene delatnosti

Oblici organizovanja zdravstvene delatnosti variraju kroz istoriju, i povezani su s razvojnim putem društvene zajednice. Zdravstvena delatnost podleže principima organizovanja postavljenim kroz rad zdravstvenih radnika u institucijama, koji u radu koriste principe medicinske doktrine, pomoću zdravstvene tehnologije, a sve to pridržavajući se propisa koji su u tu svrhu doneseni. Isto pokazuje interes društvene zajednice, da ne dozvoli spontanost u oblikovanju sistema zdravstvene zaštite, već se istome pristupa sa visokom ozbiljnošću. Strukturalni principi organizovanja zdravstvene zaštite regulišu se propisima, kao npr. Zakonom o zdravstvenoj zaštiti Federacije Bosne i Hercegovine, kao nivoi zdravstvene delatnosti:

- primarni nivo zdravstvene delatnosti,
- sekundarni nivo zdravstvene delatnosti,
- tercijarni nivo zdravstvene delatnosti.

Jedna od ključnih odluka u životnom ciklusu organizacije, jeste odluka o spajanju, udruživanju, preuzimanju ili drugom obliku sjedinjavanja s drugom organizacijom, kojim se mijenjaju obrisi i granice vlastite organizacije. „Granice se mogu menjati u tri različita smera: horizontalno, vertikalno i korporativno. Horizontalne granice odgovaraju na pitanje: koliko tržišta poduzeće opslužuje ili koliko je veliko? Vertikalne granice integracije se odnose na različite aktivnosti koje poduzeće samo obavlja i onoga što kupuje od specijaliziranih poduzeća na tržištu. Korporativne granice se odnose na set posebnih poslova u kojima poduzeće konkuriše.“ (Milosavljević, 2012).

Ne smiju se zanemariti tehnološki i organizacioni aspekti integracije, jer je u pitanju promjena koja treba da rezultira organizacionom formom sa nižim ukupnim troškovima, uz prošireno područje dejstva, sa povećanom aktivnosti u delatnosti, sa većim tržišnim učešćem na polju zdravstva.

Odluka o integrisanju se ne donosi pod pritiskom niti nakon parcijalne analize. Uspešno sprovedena strategija integracije može da vodi do većih prihoda i dobiti, ako se obavi bez velikih investicijskih i pratećih troškova.

Nerealno je očekivati da jedna javna ustanova može potpuno obavljati sve svoje funkcije, ali se konceptom integrisanja zdravstvenih ustanova može postići veće pokriće funkcija na jednoj lokaciji, pa i u manjoj zajednici.

Primarni nivo zdravstvene delatnosti

Polazeći od potreba stanovništva na lokalnom nivou, bitnu osobinu primarnog nivou zdravstvene zaštite čini rad u timovima, koji uglavnom se sastoje od jednog lekara i medicinske sestre. Ustanove primarnog nivoa zaštite su u zakonima o zdravstvenoj zaštiti u BiH navedene u velikom broju oblika: dom zdravlja, ambulanta porodične medicine, centar za mentalno zdravlje, centar za fizikalnu rehabilitaciju, hitna medicinska pomoć, ustanova za zdravstvenu brigu u kući, palijativna njega, ustanove socijalne zaštite.

U završnim odredbama Zakona o zdravstvenoj zaštiti Federacije BiH se napominje, da stručni timovi primarnog nivoa sarađuju sa sekundarnim nivoom zdravstvene zaštite. Uvođenjem integriranog modela zdravstvene zaštite, pojedine delatnosti primarnog nivoa mogu da obavljaju deo usluga i za sekundarni nivo kao što su: laboratorijske usluge, radiološke, ginekološke, pedijatrijske i druge, ako su ispunjeni kadrovski, prostorni i tehnički uslovi.

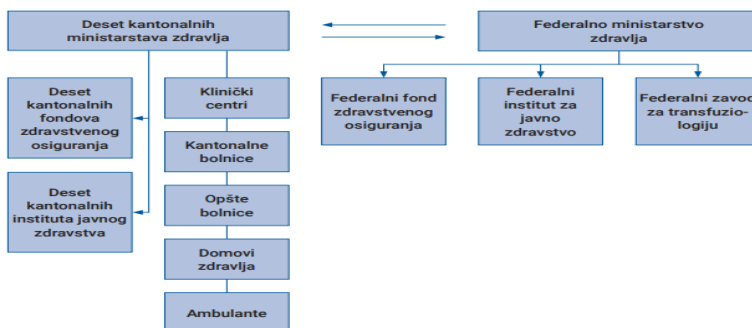
Sekundarni nivo zdravstvene delatnosti

Količina novčanih, materijalnih i ljudskih resursa, koja se troši na jednog pacijenta na sekundarnom ili na tercijarnom nivou zdravstvene zaštite, višestruko je veća u odnosu na primarni nivo. Lečenje se obavlja kroz izvanbolničku ili kroz bolničku delatnost. Cilj ovakvog organizovanja je bolja iskorišćenost medicinskih kapaciteta, uz opskrbljenost stanovništva specijalističkim uslugama. Zakon predviđa više vrsta zdravstvenih ustanova sekundarnog nivoa: poliklinika, bolnica, zavodi, univerzitetsko- klinička bolnica, lečilište, centar za dijalizu. Delatnost u sklopu specijalističko- konsultativne delatnosti čine npr. ORL, ginekologija, hirurgija, neurologija, radiologija itd. Element sekundarnog nivoa je i bolnička zdravstvena delatnost, u opštim ili specijalnim ustanovama, a odnosi se na: dijagnostiku, kurativu, rehabilitaciju, njegu, boravak i opskrbu bolesnika.

U okvirima sekundarnog nivoa zdravstvene zaštite treba uočiti onu vrstu ustanove, koja bi uz potrebne izmene, mogla da služi kao polazni oblik za integrisanje sa ustanovom primarnog nivoa zdravstvene zaštite. Organizovanje integrisanih zdravstvenih ustanova na sekundarnom nivou zdravstvene zaštite može paralelizmom, bez velikih strukturnih promjena, uvrstiti pojedine delove primarne zaštite u spektar usluga bolničke ustanove.

Tercijarni nivo zdravstvene delatnosti

Zakoni propisuju da tercijarna zdravstvena zaštita daje najsloženije usluge medicinskog pokrivanja, te edukaciju za medicinsku struku. Ustanove koje spadaju u tercijarni nivo zdravstvene zaštite su specijalizovane klinike, kliničke bolnice, kliničko-bolnički centri, zavodi za zaštitu zdravlja, zavod za transfuzijsku medicinu, zavod za radiologiju, zavod za medicinu rada.



Slika 1. Grafički prikaz strukture sistema zdravstvene zaštite u Federaciji BiH (Martić, i Đukić, 2018).
Figure 1. Graphic representation of the structure of the health care system in the Federation of BiH (Martić, & Đukić, 2018).

U sledećoj tabeli navedene su delatnosti obe vrste zdravstvenih ustanova, prema odredbama Zakona o zdravstvenoj zaštiti Federacije BiH. Vidljivo je, od pobrojanih dvanaest delatnosti doma zdravlja, njih četiri ili pet su delatnosti opšte bolnice. Druga slika efekata integrisanja bi se dobila uvrštavanjem i nemedicinskih službi uz skoro svaku javnu zdravstvenu ustanovu: prevoz, računovodstvo, pravna služba, kadrovska služba, IT, opšta administracija, obezbeđenje, održavanje.

Tabela 1. Uporedni pregled delatnosti opšte bolnice i doma zdravlja.

Table 1. Comparative overview of general hospital and health center activities.

Opšta bolnica	Dom zdravlja
Specijalističko-konsultativna delatnost	Zdravstvena zaštita nespecifičnih i specifičnih plućnih oboljenja
Anestezija i reanimacija	Zaštita reproduktivnog zdravlja žena
Citološka, mikrobiološka i biohemijska dijagnostika	Higijensko-epidemiološka zaštita
Bolnička apoteka	Apotekarska i druge srodne delatnosti
Transfuziološka delatnost krvi i krvnim sastojcima	Delatnost polivalentnih patronažnih sestara u zajednici
Snabdivanje lijekovima i medicinskim proizvodima	Zdravstvena zaštita djece
Radiološka, laboratorijska i druga dijagnostika	Laboratorijska i radiološka dijagnostika primarnog nivoa
Urgentno zbrinjavanje	Hitna medicinska pomoć
Medicinska rehabilitacija	Fizikalna i mentalna rehabilitacija u zajednici
Patologija	Specifična zdravstvena zaštita radnika
Mrtvačnica	Delatnost porodične medicine
	Zubozdravstvena zaštita

Sprovođenje stratejskih odluka o integrisanju zdravstvenih ustanova na primarnom i sekundarnom nivou zaštite zahteva prethodnu analizu stanja, broja i vrste zdravstvenih ustanova, veličine i opreme kapaciteta, stanovnika koje ustanove opslužuju, specifičnosti lokacija, posebnih potreba područja, razvojnih tendencija, finansijske snage i sličnog. Donosioci odluka o organizovanju zdravstvenih ustanova, pri osnivanju ustanove drugačijeg tipa od propisima predviđenog, imaju odgovornost za odluke koja će implicirati promenama načina korištenja zdravstvene zaštite.

Prednosti integracije zdravstvenih ustanova su značajne, u aspektu uštede u mnogim vrstama troškova, dok s druge strane, postoje opasnosti nastanka troškova koji nisu bili planirani pre ili tokom procesa spajanja. Proces integrisanja zahteva i precizno ugovorno definisanje odnosa, jer nedovoljno pripremljeno spajanje postaje izvor problema, konflikta i nezadovoljstava, uz negativne efekte za sve učesnike. Namera da integracija stvori novi kvalitet poslovanja može izazvati komplikaciju koje se reflektuju ne samo na pacijente, već i na davaoce usluga, ukoliko nadležnosti u pogledu obavljanja i naknade za uslugu nisu usaglašene. Zahteva se precizno definisanje odnosa između integrisanih ustanova, jer nastaje složenija struktura od prostog zbira pojedinačnih ustanova. Pored tog, unutrašnji organizacioni putevi su drugačiji u jednostavnijim strukturama, te se sprovođenje integracije poklapa s uređivanjem organizacije, opisima poslova, nadležnostima, rasponom rukovođenja, hijerarhijskim strukturama, izvršiocima i naredbodavcima.

ISTRAŽIVAČKI INSTRUMENTI I METODE

U okviru istraživanja primenom PEST analize u obliku PESTL, traženi su relevantni stavovi o upitnoj materiji. Zakon o zdravstvenoj zaštiti Federacije BiH odredio je mjesto istraživanja, prikupljanjem odgovora na upitniku sa zatvorenim tipom pitanja i Likertovom skalom. „U ovom sektoru opšteg okruženja analiziraćemo zakone, propise, sudske odluke i političke faktore koje vlada trenutno provodi na federalnom, državnom i lokalnom nivou“ (Coulter, 2010.). Činjenica da su osnivači javnih zdravstvenih ustanova organi ili dijelovi države, naglašava značaj pravnog, političkog i socijalnog faktora. Aktivnosti razvijanja novih formi organizovanja zdravstva moraju biti odobrene od nadležnih organa, a iste će biti, na kraju procesa reorganizacije iskazane u normativnim aktima države.

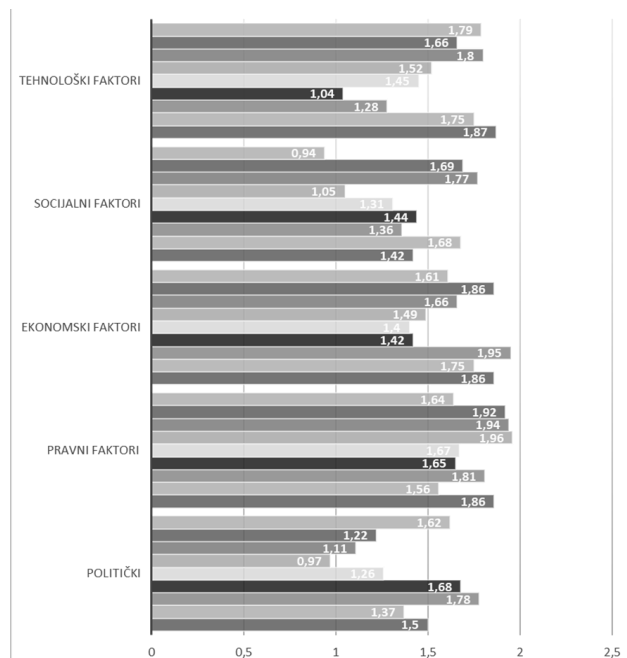
Traženi su učesnici u donošenju propisa za oblast zdravstva, saradnici u finansiranju javnog sektora zdravstva, spoljni saradnici zdravstvene ustanove i zaposlenici višeg ranga u zdravstvenoj ustanovi. Ocjene iskazane u upitniku je dalo 20 stručnjaka u zdravstvu, koji imaju dokazana ili rukovodeća znanja o delatnostima zdravstvene zaštite. Istraživanje je sprovedeno slanjem upitnika odabranim ispitanicima, juna i jula 2024. godine, uz konsultacije. Ispitanici su trebali da iz 5 grupa faktora sa po 9 vrsta uticaja, odaberu njima značajne, ocijene uticaj u rasponu od -5 do +5 i intenzitet uticaja od 1 do 10.

REZULTATI I DISKUSIJA

Iz anketnih upitnika, intenzitet uticaja je umnožen sa bodovima uticaja faktora, a prikazani su prosječni zbirovi umnožaka intenziteta faktora.

Tabela 2. Faktori opšteg okruženja.
Table 2. General environment factors.

FAKTORI	Tehnološki	Socijalni	Ekonomski	Pravni	Politički
Σ	1416	1266	1500	1601	1251
σ	139	167	167	178	139



Slika 2. Ocjene pojedinih uticaja faktora okruženja.
Figure 2. Ratings of certain environmental factor impacts.

Prikazani faktori okruženja imaju najmanji prosječni zbir na polju političkih i socijalnih elemenata. Umjesto podrške iz političkih i socijalnih struktura društva, rezultat pokazuje najmanji zbir upravo na područjima za koja i zbog kojih se pokreće transformacija zdravstvenih ustanova i integracija sistema. Važno je saznanje, sa koje strane se očekuju otpori integracijama u zdravstvu. Rezultat pokazuje i složenost uslova u kojima zdravstvene ustanove posluju. Okruženje sadrži faktore koji pomažu rad ustanove ili ga otežavaju, ali se procesom integrisanja ustanova, novim uslugama ili uštedama troškova, može umanjiti negativno dejstvo pojedinih faktora.

ZAKLJUČCI

Svi naponi učinjeni u pravcu integrisanja zdravstvenih ustanova mogu da budu poništeni u slučaju neprepoznavanja mjesta i nove uloge unutar javnog zdravstvenog sistema. Integrisanje zdravstvenih ustanova može se shvatiti kao povoljna okolnost za smanjenje negativnih uticaja iz okruženja, te da se kao nova šansa, dobije povjerenje korisnika zdravstvenih usluga. Uspješno povezivanje manjih zdravstvenih ustanova ne umanjuje potrebu da se novoformirana ustanova, efikasno uvede u zakonske okvire zdravstvenog sistema. Uspješan rezultat rada svake zdravstvene ustanove, ne treba da se svodi samo na pozitivne brojeve u izvještajima, već i na dobro opšte zdravstveno stanje stanovništva koje se opslužuje, uz visoko zadovoljstvo korisnika usluga. Zadovoljstvo korisnika je teže postići nego uštede u troškovima ili puko ostvarenje viška prihoda nad rashodima. Cilj rada je u pokušaju prikaza korisnosti pružanja većeg broja i vrste medicinskih usluga na jednom mestu, uz uštede vremena za pacijente, smanjenje troškova izbegavanjem dupliranja određenih poslova, te pretvaranje postignutih ušteda u viši kvalitet i koristi za svoje zaposlenike.

Iako je osnovna ideja rada sadržana u pojmu integrisanja, isti ne treba shvatiti dogmatski niti provoditi integrisanja zdravstvenih ustanova u onim sredinama, u kojim ustanove uporedno funkcionišu kvalitetno i nesmetano, a efekti njihovog rada zadovoljavaju i više kriterijume uspešnog poslovanja.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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POSSIBILITIES AND ASPECTS OF INTEGRATION IN PUBLIC HEALTH CARE INSTITUTIONS

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ABSTRACT

The integration of public health institutions illustrates an insufficiently implemented process, and the public health network is not based on functional integration. There are barriers between public health institutions, and their removal has not yet met the needs of users.

Legal provisions have provided opportunities for integrating health institutions that include parts of primary and secondary levels of care. In Bosnia and Herzegovina, there is no single public health institution organized according to the proposed model. Duplication of medical services is common when patients move from one health institution to another, which results in a waste of time and money.

The subject of this research is primary and secondary public health institutions and their optimal organization in terms of costs and quality through integration.

The research problem is use of different organizational structures in healthcare, limited by a lack of personnel, equipment, funding, and rising costs.

The result of the research suggests that different organizational models for public health can achieve better utilization of available resources in primary and secondary healthcare. Criteria for healthcare integration include economic, functional, medical and organizational aspects, but their implementation depends on the will of healthcare policymakers.

Keywords: health institution, medical care level, integration of health institutions.

BENČMARKING KAO METOD UPRAVLJANJA U INDUSTRIJSKIM KAPACITETIMA ŽELJEZNICA RS

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SAŽETAK

Benchmarking u Željeznicama RS je proces koji predstavlja mjerenje i upoređivanje najznačajnijih tehničko-thnoloških, ekonomskih i finansijskih pokazatelja uspješnosti proizvodnje dijelova i sklopova željezničkih vozila i usluga održavanja u radioničkim kapacitetima Doboju, Banja Luka i Prijedor i poređenju sa najboljim, unutar područja djelovanja poduzeću i izvan njega.

S obzirom na specifičnosti preduzeća Želznica RS, u radu je predložen benchmarking kao proces koji je primjenljiv i efikasan metod upravljanja, a vršio bi se u četiri faze od kojih svaka ima svoje korake. Pored navedenog, opisana je ulogu i značaj benchmarkinga u Željeznicama RS kao i metode kojom bi se uspoređivale najznačajnije performanse unutar poduzeća s boljim ili najboljim u sistemu koji se bave istom problematikom u radioničkim kapacitetima.

Analizom bi bio mjerljiv i utvrđen pokazatelj uspješnosti poslovanja sva tri radionička preduzeća, te predložena određena odstupanja u pojedinim indikatorima uspješnosti poslovanja pojedinih radioničkih kapaciteta.

Benchmarking je proveden na temelju dostupnih, tehničko-tehnoloških, ekonomskih i finansijskih podataka iz proizvodnih i uslužnih radioničkih kapaciteta koje se bave održavanjem željezničkih vozila u Doboju, Banjoj Luci i Prijedoru.

Ključne reči: benchmarking, konkurentnost, efikasnost, poređenje, parametri i ciljevi.

UVOD

Kroz rad se opisuje benchmarking u menadžmentu i njegov sveobuhvatni doprinos u privredi a i kao sveobuhvatna preporuka za kompaniju Željeznice RS koje u sopstvenim industrijskim tj. radioničkim kapacitetima obavljaju složene proizvodne procese i usluge održavanja te bih mogle da ih upoređuju sa industrijskim kompanijama koje dobro i uspješno posluju i na taj način poboljšaju i povećaju ukupnu dobit (Bešić, i Sajfert, 2005).

Dolaskom i primjenom benchmarkinga u industrijskim preduzećima uspostavlja se monitoring i izrada profesionalnih studija koje se odnose na industrijske primjenjive prakse uspješnih kompanija. Sprovođenje benchmarkinga u industrijskim kompanijama, kao i u sertifikovanim radioničkim kapacitetima za održavanje lokomotiva, putničkih i teretnih vagona i vozila za željezničke svrhe u okviru Sektora za održavanje šinskih vozila u Željeznicama RS, treba da ima svoju prepoznatljivu i veoma široku upotrebu u industriji kako bi ista iznjedrila svoj puni efekat (Kalučanin, 2020).

Cilj rada je da se postigne što veće djelovanje na kompanije, pa tako i na same Željeznice RS i ukupan željeznički sistem u BiH i okruženju, a sve u namjeri objedinjavanja korisnih tehničkih i drugih informacija koje će im biti od značaja da poduzmu poslovne radnje i aktivnosti na unapređenje tehnološkog procesa proizvodnje i davanja boljih usluga korisnicima.

BENČMARKING KAO METOD UPRAVLJANJA U INDUSTRIJI

Benčmarking se u osnovi pojavio prvo u teoriji i praksi menadžmenta odnosno upravljanja početkom devedesetih godina prošlog vijeka. U to vrijeme se pojavila i prva studija iz ove oblasti, pod nazivom „Potraga za industrijski najboljim praksama“.

Među prvim kompanijama koja je počela uspješno da koristi benčmarking na naučnoj osnovi, bila je poznata korporacija „Xerox“. Menadžment rukovodstva ove korporacije je benčmarkingom uspio da se suprostavi svjetskoj konkurenciji. U narednim godinama ova korporacija je poslije primjenjenog benčmarkinga uspjela da proizvodi bolje aparate za fotokopiranje, po manjim cijenama, sa značajno umanjenim troškovima korištenja i održavanja, bolje dizajniranih i kvalitetnijih performansi koje su kupci tražili.

Među mnogobrojnim definicijama benčmarkinga neophodno je izdvojiti neke koje je dao tvorac benčmarkinga Camp: „Benčmarking je permanentan proces mjerenja proizvodnje, usluga i prakse kompanije prema najuspješnijima ili kompanijama koje se smatraju za industrijske lidere“. Po Vottsomu to je „stalna potraga za primjenom znatno boljih praksi koje vode do superiornijih rezultata“.

U svojoj biti, benčmarking uključuje sistemski i kontinuiran proces mjerenja i upoređivanja poslovnih procesa jednog preduzeća u odnosu na poslovne procese lidera bilo gdje u svijetu. Cilj tih procesa je dobijanje potpunih informacija koje će pomoći kompaniji da poduzme aktivnosti za unapređenje svojih performansi i što veće primjene industrijskog inženjerstva, menadžmenta i ekonomije u industriji (Adamović, 2008; Stević, 2011).

Realno sagledavanje potrebe za benčmarkingom je jedno od najvažnijih pitanja u strategiji vođenja preduzeća. Od iznalaženja jasnog odgovora na njega u značajnoj mjeri ovisi uspješnost primjene najboljih rješenja. Svakako da je to logično, jer rezultate industrijske proizvodnje nećemo povećati samo inteziviranjem proizvodnje, uvođenjem tehnologije, već pre svega razvijanjem osećaja i potrebe za korišćenjem industrijskih proizvoda u različite svrhe. Kada povećamo potrebu, na primer za automobilom, onda se refleksno javlja interakcija i za povećanjem proizvodnje, a sa njom i novi konjunkturi trend u cijeloj privredi (povećanje iskorišćenosti kapaciteta, povećanje uposlenosti, rast kupovnih fondova itd.) (Flir Systems AB, 2007).

Potreba za benčmarkingom je posebno značajna za naše društvo i privredu, među kojima su i Željeznice RS, jer je svi su godinama nastojali da izgrađuju sopstvenu praksu i da traže „originalna“ rješenja koja svijet ne poznaje, a kritikujući, ili omalovažavajući najbolja rješenja i praksu, pravdajući da je ona nepodesna za novo, navodno humano društvo koje se izgrađuje. Rezultati ovakvog shvatanja su poznati, što nameće da se o benčmarkingu kao tehnici savremenog menadžmenta treba posvetiti dužna pažnja od strane privrede i društva u cjelini (Adamović, 2011, 2013).

BENČMARKING I DEFINISANJE REZULTATA

Svi privredni subjekti teže da u narednom višegodišnjem periodu mnogo bolje posluju nego u prethodnom. Te činjenice svaki lider i tim mora da uzme u obzir prilikom objedinjavanja relevantnih informacija o procesima u preduzeću kojim upravlja, kao i u preduzećima od kojih treba učiti i prikupljati dragocjena iskustva.

Posebno, benčmarking treba primijeniti u djelatnostima gdje se postižu najslabiji rezultati. Ova primjena se preporučuje Željeznicama RS u kapacitetima za proizvodnju komponenti, održavanja vozničkih sredstava i pružanja usluga imaojcima željezničkih vozila jer postojeći poslovni rezultati nisu im na zavidnom nivou (EiOGas, 2024).

Osnovni ciljevi ove faze su:

- Razumijevanje procesa koji će biti obuhvaćen korjenitom promjenom;
- Određivanje željenog učinka korjenite promjene;
- Izbor i poboljšanje procesa;
- Utvrđivanje onoga što jeste ili nije moguće, kao i određivanje parametara.

Primjena benčmarkinga predstavlja međusobnu razmjenu tehničkih i drugih informacija sa uspješnim kompanijama bez obzira da li pripadaju istoj djelatnosti. Osnovna namjera i uloga je

utvrđivanje tajne uspjeha vodećih preduzeća, a potom primjena značajnih znanja i iskustava. To je korak naprijed za svaku kompaniju, kao što bih bio i za Željeznice RS, u odnosu na puko kopiranje poslovanja drugih preduzeća koje rijetko daje dobre rezultate.

Primjena tuđih iskustava i znanja podrazumijeva mjerenje i dokumentovanje toka aktivnosti u procesu. Pri tome može se koristiti interni benčmarking (upoređuje se sa jednim odjeljenjem) i eksterni benčmarking (postupci preduzeća se upoređuju sa postupcima preduzeća koje je srodne djelatnosti, sa glavnim konkurentima ili sa postupcima preduzeća koja nemaju srodnu djelatnost, niti su konkurenti, ali su vodeći u svojoj djelatnosti).

Informacije benčmarkinga obično sadrže i određene greške, što se mora uzeti u obzir prilikom analize i razmatranja istih. Naročito je teško vršiti upoređivanje podataka benčmarkinga postojećih procesa sa potencijalnim rezultatima koji proističu iz procesa korjenitih promjena.

Odluka o korišćenju najboljih postupaka bi trebalo da bude zasnovana na odgovorima na tri krucijalna pitanja:

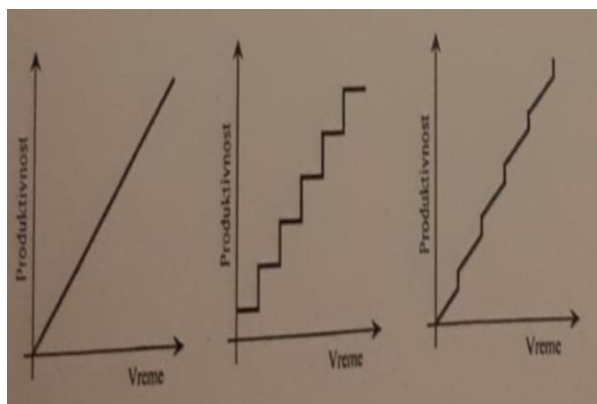
- Da li taj postupak omogućava konkurentnu prednost koja je mjerljiva i vidljiva?
- Da li taj postupak nudi najpovoljnije vrijednosti akcija ili prednosti prilikom njegove primjene, u odnosu na troškove i uloženi napor?
- Da li taj postupak obezbjeđuje koristan model za sva preduzeća koja su u njega uključena, a ne samo na konkurente ili članove iste grane industrije?

Cilj ove grupe koraka u procesu promjena je procjena statusa, mogućnosti, efikasnosti i usmjerenosti informatičke tehnologije preduzeća i njihove povezanosti sa vizijom i strategijom preduzeća u kojem je izvršena korjenita promjena.

U praksi je da se uspješnim korjenitim promjenama postignu nekoliko puta bolje vrijednosti od standardnih, odnosno benčmarking vrijednosti.

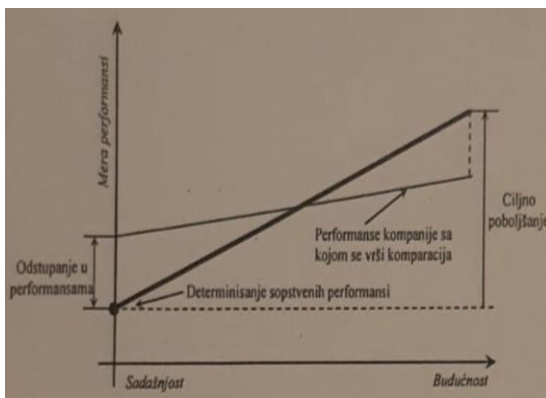
Treba vršiti procjenu ponašanja povezanih sa procesima za koje su ranije određene standardne vrijednosti i potom birati najpodesniji postupak koji bi trebalo primijeniti i poboljšati.

Zbog različitog shvatanja benčmarkinga, obzirom na različitu proizvodnu filozofiju, mogu se očekivati tri modela povećanja produktivnosti preduzeća (Slika 1).



Slika 1. Kombinovani modeli povećanja produktivnosti preduzeća.
Figure 1. Combined models of increasing company productivity.

Ova faza je značajna u pogledu analitičke sposobnosti pronalaženja veza između performansi i faktora performansi. Kroz proces analize identifikuju se sličnosti i razlike između kompanija koje se upoređuju. Akcenat je na identifikovanju razlika, odnosno identifikovanju procesa, procedura, aktivnosti, praksi koje se obavljaju bolje, superiornije, odnosno procesa koji mogu i treba da budu unaprijeđeni. Proces identifikovanja i eliminisanja odstupanja u performansama dat je na slici 2.



Slika 2. Proces identifikovanja i eliminisanja odstupanja u performansama.
Figure 2. The process of identifying and eliminating performance deviations.

ZAKLJUČCI

Ovaj rad pokazuje da benčmarking obuhvata širi spektar permanentnih procesa sagledavanje proizvodnje, usluga i prakse same kompanije prema najuspešnijim ili kompanije koja se u određenoj djelatnosti značajno ističe i koja bise smatra za vođu u određenim industrijskim oblastima.

Jedno od bitnih pitanja u strategiji upravljanja preduzećem, što na svojevrsan način potvrđuje i ovaj rad, je sagledavanje stvarne potrebe za benčmarkingom.

Iz rada proističe da se benčmarking primenjuje u oblastima gdje se postižu nedovoljno dobri rezultati poslovanja u kompanijama.

Prisutna različitost shvatanja benčmarkinga kroz različitu proizvodnu filozofiju, za očekivati je više modela povećanja produktivnosti u kompaniji. Ti modeli će dati doprinos u identifikovanju razlika, odnosno procesa, procedura, aktivnosti, praksi koje se obavljaju bolje tj. procesa koji trebaju da se unaprijede.

Na osnovu svega može se zaključiti da Željeznice RS i drugi željeznički sistemi u BiH i okruženju, zbog višegodišnjeg nezadovoljavajućeg poslovanja, kao dio privrede u industriji Republike Srpske i BiH ili drugih država, trebaju primjeniti benčmarking kao metod upravljanja u povećanju proizvodnje i usluga i ostvarivanju boljih poslovnih rezultata rada za kompanije u budućnosti.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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BENCHMARKING AS A MANAGEMENT METHOD IN INDUSTRIAL CAPACITIES OF THE RAILWAYS OF THE REPUBLIC OF SRPSKA

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ABSTRACT

Benchmarking in the Railways of the Republic of Srpska is a process that represents the measurement and comparison of the most important technical-technological, economic and financial indicators of the success of the production of parts and assemblies of railway vehicles and maintenance services in the workshop capacities of Doboj, Banja Luka and Prijedor and comparison with the best within the company's area of operation and outside it.

Given the specifics of the Railways of the Republic of Srpska company, the paper proposes benchmarking as a process that is an applicable and efficient management method and would be carried out in four phases, each of which has its own steps. In addition, the role and importance of benchmarking in Railways of the Republic of Srpska is described, as well as methods that would compare the most significant performances within the company with better or best in the system that deal with the same problems in workshop capacities.

The analysis would measure and determine the performance indicator of all three workshop companies and present certain deviations in individual performance indicators of individual workshop capacities.

Benchmarking was conducted based on available technical-technological, economic and financial data from production and service workshop capacities dealing with the maintenance of railway vehicles in Doboj, Banja Luka and Prijedor.

Keywords: benchmarking, competitiveness, efficiency, comparison, parameters and goals.

MODEL BALANCED SCORECARD KONCEPTA U KOMPANIJU

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SAŽETAK

Uloga i značaj primene Balanced Scorecard koncepta u industrijskim preduzećima predstavlja dobru osnovu za izradu modela za merenje i analizu ključnih pokazatelja performansi (KPI's) identifikovanih procesa u preduzeću. Takođe, primena Balanced Scorecard koncepta ukazuje na potrebu njegovog prilagođavanja prirodi i karakteristikama konkretnog slučaja – branši i veličini preduzeća.

Ključne reči: Balanced Scorecard, Industrijsko preduzeće, Ključni pokazatelj performansi.

UVOD

Većina savremenih studija vezana za inženjerski menadžment fokusirana je na primenu postojećih i razvoj novih modela kojima će se postići poslovna izvrsnost. Uspostavljanje sistemskog prilaza, integracija s postojećim prilazima i modelima, te definisanje ključnih elemenata (npr. atributa metrike, područja za poboljšanje, metoda za kontrolu, identifikacija elemenata ključnih za provođenje promena). Kontrola ostvarenja strateških ciljeva vrši se provođenjem interorganizacionih merenja i njihovim poređenjem sa istorijskim podacima iz baze podataka preduzeća (List, et al., 1996). Prema tome veliki broj naučnih istraživanja se bavi problemima uspostavljanja programa merenja procesa u preduzeću. To se odnosi na uspostavljanje procesa merenja, uspostavljanje baze podataka, odabir odgovarajućeg optimalnog skupa indikatora, merenja te primenu različitih statističkih modela analize podataka radi unapređenja performansi.

Početkom devedesetih godina prošlog veka razvijen je nov sistem za merenje performansi poslovanja organizacije pod nazivom Balanced scorecard – BSC (Koncept uravnoteženih pokazatelja poslovanja), koji je u početku bio sredstvo izveštavanja, ali je on i tada uključivao kritičke aspekte poslovanja.

Balanced Scorecard – je novi koncept predstavljen od strane Roberta Kaplana i Davida Nortona krajem prošlog veka kao revolucionarno novi sistem za merenje performansi (Kaplan & Norton, 1999).

Model Nortona i Kaplana – Balanced Scorecard, nastao je kao rezultat istraživanja sistema za merenje performansi koji su se koristili u praksi i potreba savremenih preduzeća, s obzirom na uslove u okruženju i osobenosti poslovanja.

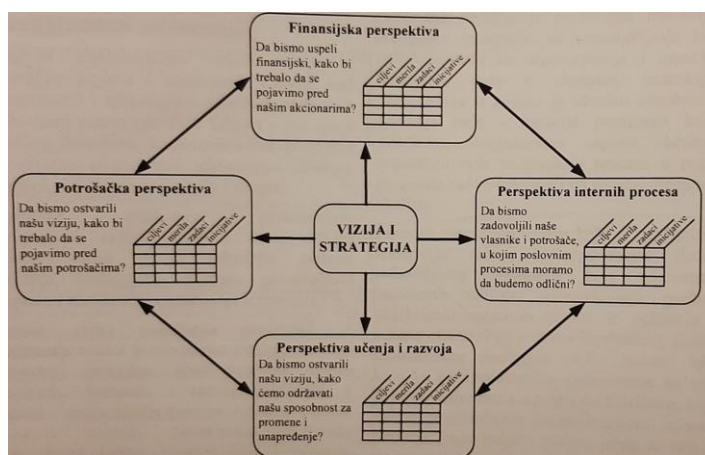
Balanced Scorecard je kao i svi savremeni sistemi merenja uspešnosti poslovanja nezamisliv bez informatičke podrške. Složenost poslovnog okruženja i preduzeća danas je takva da preduzeće za merenje uspešnosti mora koristiti brojne informacije i preraditi ogromne količine podataka, što može ostvariti samo uz pomoć odgovarajuće informatičke podrške. Dobro izgrađen informacioni sistem se pokazao kao jedan od značajnijih faktora uspešne izgradnje i implemetacije BSC (Kaplan & Norton, 2001).

OSNOVNI ELEMENTI BALANCED SCORECARD

Model Balanced Scorecard meri ukupnu uspešnost preduzeća kombinovanjem finansijskih i nefinansijskih pokazatelja, raspoređenih u okviru četiri perspektive (kako je predloženo u originalnom modelu). Pokazatelji u okviru finansijske perspektive predstavljaju pokazatelje rezultata (*lagging indicators* – zaostajući indikatori), dok pokazatelji ostalih perspektiva daju rane signale (*leading indicators* – vodeći indikatori) i ukazuju na potrebu korektivne akcije. Ukoliko je adekvatno implementiran model, putem ciljeva i njihovih međusobnih odnosa, treba zapravo da prikaže samu strategiju preduzeća (Gajić, 2004).

Ciljevi i njihova merila – merila performansi, prema konceptu Balanced Scorecard, izvode se iz vizije i strategije preduzeća. Ciljevi i njihova merila definišu se iz četiri perspektive:

- finansijske perspektive,
- potrošačke perspektive,
- perspektive internih poslovnih procesa, i
- perspektive učenja i razvoja (Kaplan, & Norton, 2001) (Slika 1).



Slika 1. Model Balanced Scorecard (Kaplan, & Norton., 2001).

Figure 1. Balanced Scorecard Model (Kaplan, & Norton., 2001).

Većina uspešnih preduzeća i pre pojave BSC-a formulisala je ciljeve i merila performanse po različitim osnovama sa osnovnom svrhom tehničke kontrole kratkoročnih operacija (poslovnih odluka). Međutim, ovakvi sistemi merila performansi nisu bili uravnoteženi (balansirani). Balanced Scorecard upravo obezbeđuje ovu ravnotežu po tri osnova:

- ravnoteža između eksternih merila koja se odnose na akcionare i potrošače i internih merila koja se odnose na interne poslovne procese i učenje i razvoj;
- ravnoteža između merila uspeha, kao rezultata prošlih akcija i merila budućih performansi;
- ravnoteža između objektivnih merila uspeha, lakih za kvantifikovanje i subjektivnih i kvalitativnih merila performansi.

Preduzeće treba da u svim utvrđenim perspektivama identifikuje kritične faktore uspeha, a u okviru njih merila preko kojih će nadzirati ostvarenje strateških ciljeva i meriti uspešnost poslovanja, odnosno efikasnost u posmatranom periodu.

Indikatori performansi postaju ključni elementi kojima preduzeće uči na osnovu iskustava prošlosti i uslovljavaju promene koje se uvode radi poboljšanja performansi u budućnosti.

Procesni model složene kompanije

Industrijska preduzeća predstavljaju organizacione celine, koje u datoj okolini ostvaruju svoju misiju određenu svrhom postojanja, strategijom dejstava, pokretačkim polugama i standardima ponašanja u okolini (Zelenović, 1984).

Osnovna svrha postojanja preduzeća je snabdevanje tržišta proizvodima i uslugama, koji obezbeđuju potreban nivo kvaliteta života zaposlenih, opstanak i razvoj preduzeća u vremenu i zadovoljenje potreba društava u kome preduzeće posluje. Uslovi u kojima preduzeće ostvaruje svoju misiju su kompleksni, nestabilni i krajnje neizvesni, što zahteva aktivnu ulogu menadžmenta, koji poseduje znanje, želju i veštine da upravlja funkcionisanjem i razvojem preduzeća.

Jednom uspostavljena organizaciona struktura industrijskog preduzeća ne može biti zadovoljavajuća za duže vreme, a posebno ne trajno. Stalne promene u tržišnom i ukupnom okruženju nameću imperativ menadžmentu da stalno usavršava organizacionu strukturu industrijskog preduzeća kako bi stekao, očuvao i unapređivao njenu poziciju na tržištu, a time doprinosio njenoj poslovnoj uspešnosti.

Prethodna objašnjenja poslovanja industrijskog preduzeća omogućili su uspostavljanje takođe opštih modela za organizovanje i upravljanje procesima rada u složenim industrijskim preduzećima u kojima je utvrđen određen broj područja rada – funkcija preduzeća koje u skladnom, intergrativnom naporu obezbeđuju realizaciju svih neophodnih procesa u pogledu programa rada i veličine i na relaciji preduzeće – okolina.

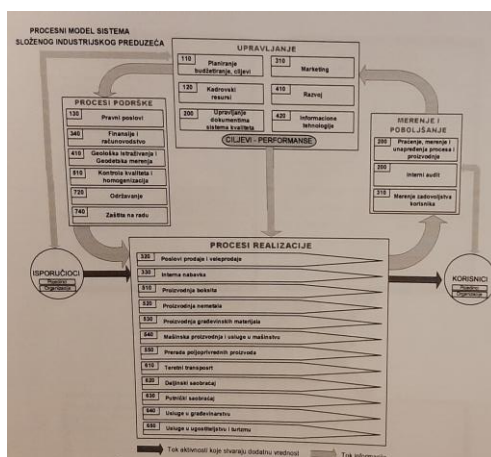
Put da se savladaju ove brze promene jeste da se kreira fleksibilna organizaciona struktura koja se može brzo prilagoditi, često neočekivanim promenama i šansama. Klasilne, krute organizacione strukture su prošlost i njihovo zadržavanje u nekim industrijskim preduzećima označava njihovu nemoć da uvažavanjem promena osiguraju budući razvoj. Takođe, prilagođavanje promenama uslovljava organizaciju da proširuju svoje delatnosti.

Danas, ovako složeno industrijsko preduzeće ima razgranatu organizacionu strukturu, a samim tim i komplikovane međusobne veze između procesa, pa je upravljanje preduzećem složeno.

Svaka funkcionalna aktivnost u primeru složenog industrijskog preduzeća ima svoje posebne radne procese kojima se upravlja tako da se poslovi obavljaju na način koji osigurava stabilne veze, čiji je cilj da se posao u celini efikasno završava. Radi efikasnog upravljanja identifikovani su procesi, koji predstavljaju osnovu za funkcionisanje sistema menadžmenta kvalitetom (QMS-a) u posmatranom preduzeću.

Struktura identifikovanih procesa i njihove međusobne veze su prikazani procesnim modelom na originalnom primeru složenog industrijskog preduzeća (slika 2), koga čine sledeće grupe procesa:

- Prosesi upravljanja
- Prosesi realizacije
- Prosesi podrške
- Prosesi merenja i poboljšanja



Slika 2. Procesni model sistema industrijskog preduzeća.
Figure 2. Process model of an industrial enterprise system.

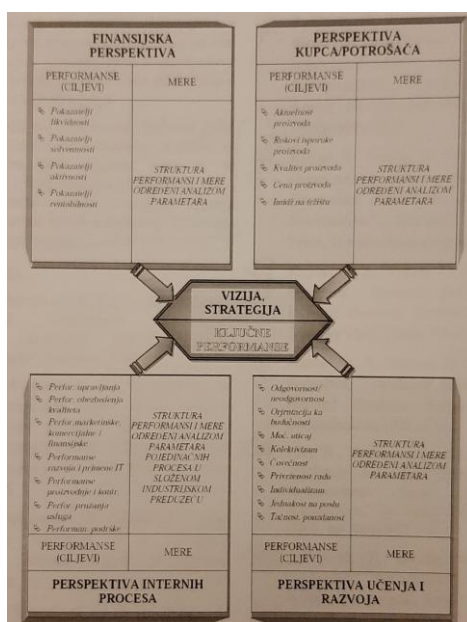
BALANCED SCORECARD KOMPANIJE

Praktične realizacije Balanced Scorecard koncepta, ukazuju na potrebu njegovog prilagođavanja prirodi i karakteristikama konkretnog slučaja (tj. branši i veličini preduzeća) kako je prikzano na slici 3 (Đurić, 2010; Đurić i sar., 2010, str. 890-902).

U praktičnim realizacijama primene Balanced Scorecard koncepta neophodno je identifikovati ključne pokazatelje performansi industrijskog preduzeća u sva četiri navedena područja posmatranja, uz jasno naglašenu potrebu da se merila u tim područjima posmatranja standardizuju do nivoa koji obezbeđuje interne i eksterne potrebe preduzeća – bez „opterećivanja“ pojmovima finansijski, tehnički ili nefinansijski.

FINANSIJSKA PERSPEKTIVA		PERSPEKTIVA KUPCA/POTROŠAČA	
PERFORMANSE (CILJEVI)	MERE	PERFORMANSE (CILJEVI)	MERE
➤ Sposobnost preživljavanja ➤ Sposobnost opstanka ➤ Sposobnost razvoja	➤ Pozitivan novčani tok ➤ Stalni rast prodaje i prihoda ➤ Stalni rast učešća na tržištu, prinosa na investicije (ROI) i dodatne ekonomske vrednosti (EVA)	➤ Aktuelnost proizvoda ➤ Odgovornost u isporuci ➤ Biti prioritetni dobavljač ➤ Biti partner	➤ Učešće novih proizvoda u ukupnoj prodaji ➤ Procenat isporuka na vreme ➤ Učešće u kupčevim ključnim nabavkama ➤ Broj kooperantskih ugovora sa kupcima
PERSPEKTIVA INTERNIH PROCESA		PERSPEKTIVA UČENJA I RAZVOJA	
PERFORMANSE (CILJEVI)	MERE	PERFORMANSE (CILJEVI)	MERE
➤ Tehnolotika kompetitivnosti ➤ Proizvodna izvrsnost ➤ Razvojna izvrsnost ➤ Razvojna sposobnost	➤ Kapaciteti, karakteristike opreme, modernost ➤ Proizvodni ciklus, cena koštanja, dobit ➤ Vreme od ideje do tržišta ➤ Učešće novih proizvoda u programu	➤ Kompetitivnost zaposlenih ➤ Sposobnost učenja ➤ Privrženost preduzeću ➤ Sposobnost vođenja	➤ Vreme do razvoja nove generacije ➤ Vreme do sazrevanja za procese preduzeća ➤ Procenat odlazaka iz preduzeća ➤ Karakteristike liderstva

Slika 3. Razrada koncepta Balanced Scorecard (Kaplan & Norton, 2001; Kaplan & Norton, 1999).
Figure 3. Elaboration of the Balanced Scorecard concept (Kaplan & Norton, 2001; Kaplan & Norton, 1999).



Slika 4. Koncept Balanced Scorecard prilagođen industrijskom preduzeću (Đurić, 2010).
Figure 4. Balanced Scorecard concept adapted to an industrial enterprise (Đurić, 2010).

Stjepanović, Z. i sar. (2025) Benčmarking kao metod upravljanja u industrijskim kapacitetima željeznica RS. *STED Conference 14(2)*, 155-160.

Prilaz konkretizaciji ključnih performansi procesa za slučaj složenog industrijskog preduzeća, naveden na slici 4 usvojen je imajući u vidu iskustva vodećih svetskih firmi u području primene procesnog prilaza zasnovanog na standardima ISO 9000.

ZAKLJUČCI

Jasne prednosti koje ostvaruju preduzeća koja primenjuju Balanced Scorecard su poboljšano strateško planiranje, poboljšana komunikacija strategije, bolja informisanost, poboljšano izveštavanje o performansama i bolja usklađenost strategije.

Očekuje se da promene u načinu posmatranja različitih segmenata poslovanja kroz Balanced Scorecard bitno utiču na kvalitet organizacije preduzeća i da time doprinesu poslovanju, a pre svega razvoju kompanije i bržem dostizanju strateških ciljeva i vizije preduzeća.

Primena Balanced Scorecarda koncepta u složenom preduzeću imaju značajnu ulogu jer čini osnovu za procenu i ocenu uspešnosti njegove realizacije kao komponenata ciljeva preduzeća u okviru konkurentskih strategija.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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MODEL OF THE BALANCED SCORECARD CONCEPT IN THE COMPANY

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ABSTRACT

The importance of the application of the Balanced Scorecard Concept in the industrial company, presents a good basis for building a model for measuring and analyzing Key Performance Indicators (KPI's), indentified in the Company. Also, the application of the BSC concepts points out the need for its adjustment to the nature and characteristics of the case, type and size of the Company.

Keywords: benchmarking, competitiveness, efficiency, comparison, parameters and goals.

HOW TO BUILD A GOOD SUPPLY CHAIN

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ABSTRACT

In today's competitive business environment, supply chain management (SCM) has become an indispensable part of action management, dealing with business improvement and exploring the operational actions that managers and staff need to do to drive better business performance and achieve excellence. The customers' needs are ever-changing at a galloping pace which makes an organization competitive and non-competitive based on fulfilling these needs. With increased supply chain management practices, organizations are putting more emphasis on developing their human resources across the chain to ensure adequate performance through training and retraining of their employees. A systematic literature review is presented in this paper. The supply focuses on managerial skills and abilities needed at various levels of the supply chain. The topic of supply chain management has many implications for a firm; however, in this paper, we focus only on supply chains and how they can be used to achieve success with the role of managers in the management process.

Keywords: supply chain, innovation, business strategy, competitive advantage, leadership.

INTRODUCTION

In the competitive worldwide market, organizations struggle to attain a favorable position without exceptional tactics that guarantee client satisfaction with their products or services. Strategy fundamentally involves selecting to execute operations in a manner distinct from competitors (Porter, 1996). Competitive strategy entails the intentional selection of distinct activities to provide a unique value proposition. An effective operational strategy can establish competitive capabilities that align with competitive priorities. The supply chain has four primary competitive priorities: delivery speed, variety, customization, and cost efficiency. Effective supply chain design and integration can enhance an organization's competitiveness within its industry and simultaneously improve its status as a corporate citizen. A prevalent subject among numerous organizations is the responsible management of capital, ecological, and human resources utilized in the production of their services or products. Such companies aim to provide products, services, and processes characterized by sustainability, ensuring that they fulfill what humanity requires without compromising the welfare of future generations (Krajewski, Malhotra and Ritzman, 2018).

When planning an operation's supply chain, some questions must be determined: (1) What is the importance of supply chain design in the business process? (2) Why does every company need the right supply chain? and (3) What is the role of leaders? The paper will answer these questions by analyzing and discussing the main points in more detail.

SUPPLY CHAIN AND THE IMPORTANCE OF SUPPLY CHAIN

One definition of a *supply chain* is "the network of entities involved in the production of a good or service from start to finish, including both internal and external stakeholders" (Krajewski, Malhotra and Ritzman, 2018). The term "supplier relationship management" is more precise; it refers to the interconnected systems that facilitate the exchange of services, goods, money, and information between a business and its suppliers and consumers. Bear in mind, too, that a corporation like Amazon may use a combination of supply chains, depending on the things it purchases and sells. The product or provider's ability to negotiate a successful contract can prevent

them from being a supplier in another supply chain. This could be because the supply chains are different.

A supply chain constitutes a network of enterprises. Consequently, each company within the chain must formulate its own supply chains to align with the competitive priorities of its services or products. Despite the implementation of advanced technology like as the Internet, computer-aided design, flexible manufacturing, and automated warehousing throughout all phases of the supply chain, the performance of numerous supply chains continues to be unsatisfactory. Krajewski, Malhotra, and Ritzman (2018). Strategy is characterized as a collection of diverse operations integrated to establish a distinctive and valued market position (Porter, 1996). To convert challenges into chances, firms must enhance their supply chain processes. Innovation and enhancement of firms' productivity likely to generate demand and facilitate growth in wealth (Porter and Rivkin, 2012). A potential cause of failures is because managers lack comprehension of the demand for their services or products, which hinders their ability to create supply networks that meet those expectations. Amazon exemplifies the effective customization of a supply chain to meet client demands in a marketplace that is highly competitive. Figure 1 shows the three major areas of focus in creating an effective supply chain (*Link Services of Products with Internal Processes, Link Services or Products with the External Supply Chain and Link Services or Products with Customers, Suppliers, and Supply Chain Processes*) (Krajewski, Malhotra and Ritzman, 2018).

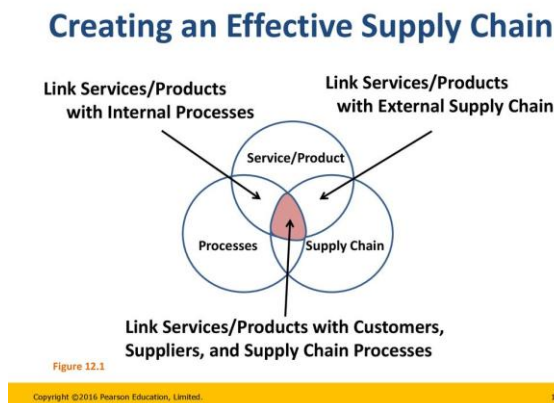


Figure 1. Creating an Effective Supply Chain (Krajewski, Malhotra and Ritzman, 2018).

Creating an effective supply chain necessitates acknowledging external competitive forces alongside internal organizational pressures from departments such as sales, marketing, and product development. Consequently, the service-profit chain must connect customer loyalty, customer satisfaction, employee loyalty, and productivity to enhance profitability (Heskett et al., 2008). An efficient supply chain design necessitates a collective endeavor from the CEO downward to address the four pressures adequately. Every functional area has an interest in an organization's supply chain decisions. Collis and Montgomery (1995) argue that organizations identify essential competitive priorities that are pivotal for enhancing market share, establishing market positioning, and improving internal process efficiency. A corporation must also consider external factors such as the threat of new entrants, substitutes, and the increasing power of customers and suppliers while formulating its strategy. A strategic initiative is valuable solely if it generates tangible benefits for customers, employees, and suppliers. Furthermore, Porter (1996) posited that the difficulty of formulating or reinstating a coherent plan is predominantly an organizational issue contingent upon leadership. Given the multitude of opposing influences influencing decision-making and trade-offs within businesses, a coherent intellectual framework to direct strategy is an essential counterbalance.

The first step in formulating an efficient supply-chain strategy is to assess the nature of demand for the items supplied by the company, determining if the products are functional or

inventive (Fisher, 1997). For example, within the conventional functional category of food, enterprises like Ben & Jerry's, Mrs. Fields, and Starbucks Coffee Company have sought to achieve a competitive advantage through unique flavors and novel concepts. Century Products, a prominent maker of children's car seats, has introduced innovation to a practical product. Companies should formulate the Optimal Supply-Chain Strategy by aligning supply chains with products, utilizing an efficient process for functional products and a responsive method for innovative products. The success of National Bicycle exemplifies a responsive supply chain attained by mitigating uncertainty.

CHOOSING THE RIGHT SUPPLY CHAIN FOR THE COMPANY

This section will address the second question. Hayes and Pisano (1994) assert that no singular strategy is universally applicable to all firms, as each organization has a distinct approach; hence, a strategy that succeeds in one company may fail in another. Consequently, any strategy selected by a corporation must be adaptable. Collis and Montgomery (1995) asserted that it is challenging to implement a uniform business plan across diverse enterprises, as no company possesses a same array of experiences, assets, talents, or organizational cultures. Furthermore, Collis (2021) noted that numerous organizations falter due to their ignorance of company value and the absence of a strategic framework. Consequently, senior executives must implement an appropriate supply chain within their firm to attain substantial competitive advantages.

In addition, Pisano (2015) suggested that a comprehensive company plan must encompass a novel variety of operational capabilities and necessitate backing from innovations. An effective strategy should have substantial effects, including enhancing customer value by increasing their desire to pay, augmenting employee value by improving job appeal, and providing supplier value by lowering operational costs (Oberholzer-Gee, 2021). Sadun, Bloom, and Reenen (2017) emphasized that effective management of fundamentals can result in elevated operational excellence, which is challenging for competitors to replicate, hence aligning with a robust corporate strategy. Furthermore, it is essential to establish strategic flexibility alongside a distinct competitive advantage and develop the capacity to attain that advantage (Hayes and Pisano, 1994).

THE ROLE OF LEADERS IN SUPPLY CHAIN MANAGEMENT

This part will answer the last question. In many organizations, leadership has deteriorated into managing operational enhancements and negotiating agreements. However, the leader's responsibilities are more extensive and far more crucial. General management encompasses more than the oversight of specific functions. An effective leader must possess an open-minded disposition and be physically present in several locations to oversee daily operations (Watanabe, 2007). He proposed that a senior management should empower subordinates with the autonomy to do their duties and responsibilities, while also facilitating open communication channels to address issues. Zeng (2018) asserted that executives must optimize the supply chain process by coordinating firm personnel, third parties, and customers to collaborate inside a network. Krajewski, Malhotra, and Ritzman (2018) underscored the responsibilities of leaders, which encompass operational processes, design, innovation, technological adaptation, workforce challenges, supply chain management, and quality control.

The core of business is in strategy: articulating and conveying the company's distinctive viewpoint, making trade-offs, and establishing coherence among activities. Lower-level managers lack the insight and assurance to uphold a strategy. There will be persistent demands to concede, mitigate trade-offs, and imitate competitors. A primary responsibility of a leader is to educate others within the organization regarding strategy and to decline requests when necessary. One of the primary functions of a clearly articulated strategy is to assist employees in making decisions that involve trade-offs in their activities and daily choices (Porter, 1996).

Why haven't the new ideas and technologies led to improved performance? Because managers lack a framework for determining which options are most suitable for their specific organizational context (Fisher, 1997). Managers must comprehend the characteristics of product demand and develop a supply chain that optimally fulfills that need. Furthermore, decisive leaders

who are prepared to make choices are crucial. Collis and Montgomery (1995) assert that in an ever-evolving environment, corporations must consistently exert pressure at the frontiers to prepare for the forthcoming competition. Managers must consistently invest in and enhance their resources, regardless of their current quality, and strategically utilize them in appealing industries to establish a competitive advantage. Managers carefully establish specific strategic objectives, allocate resources in alignment with those objectives, prioritize operational actions, promptly assess the operational and strategic ramifications of their decisions, and, if warranted, revise their strategic objectives. The closed-loop management method allows leaders to oversee both strategy and operations while balancing the inherent tensions between them (Kaplan and Norton, 2008). Managers should get judgments on essential resources from objective market data. Based on our observations, managers frequently regard core competence as an intuitive endeavor, neglecting the comprehensive investigation and meticulous analysis required to arrive at the correct conclusion (Collis and Montgomery, 1995).

CONCLUSIONS

This paper aims to analyze the significance of supply chain management as a critical determinant of a company's performance. This study identifies that competitive advantage is established via the development of an efficient supply chain and the dedication of management and the organization to engage with supply chain participants. The study indicates that managerial capabilities significantly enhance supply chain sustainability. The study illustrates the competencies and skills of managers in effectively managing the supply chain. Certain organizations have achieved success through distinct supply chain strategies, each employing varied approaches to supply chain management (Christensen et al., 2015). A general management approach applicable to all organizations does not exist (Pisano, 2015). Consequently, it is recommended that each corporation detect its internal as well as external factors to determine the most appropriate business strategy.

In addition to the efficacy of supply chain management, it is crucial to highlight the significant function of senior managers in the production process. The company's management confront the issue of being competitive by analyzing and adapting to the ever-evolving market dynamics. To navigate the rapid changes in the competitive market, contemporary leaders must be imaginative and implement unique ideas, as traditional leadership is no longer adequate. The present executives must recognize the shifts in the economy, society, technology, and science, ensuring that the company's innovation attains a high success rate rather than prioritizing operational efficiency.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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LAW SECTION
PRAVO

UVOĐENJE STROŽIJIH MJERA ZAŠTITE ŽRTAVA I STROŽIJIH SANKCIJA ZA POČINIOCE NASILJA U PORODICI U SVJETLU NOVOG ZAKONA O ZAŠTITI OD NASILJA U PORODICI I NASILJA NAD ŽENAMA U FEDERACIJI BOSNE I HERCEGOVINE

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SAŽETAK

Dom naroda Parlamenta Federacije Bosne i Hercegovine na svojoj sjednici 4. marta 2025. godine, jednoglasno je usvojio Zakon o zaštiti od nasilja u porodici i nasilja nad ženama, čime su uvedene strožije mjere zaštite žrtava te strožije sankcije za počinioc nasilja na teritoriji Federacije Bosne i Hercegovine.

U poređenju sa prijašnjim Zakonom, nove zakonske odredbe propisuju veću odgovornost i veću mogućnost djelovanja svih onih koji učestvuju u lancu odlučivanja u borbi protiv nasilja u porodici (policija, pravosudni organi, centri za socijalni rad te obrazovne institucije). U radu će biti detaljno obrazložene uvedene novine ovog Zakona: proširivanje definicije žrtve, elektronski nadzor nasilnika, sankcionisanje online nasilja, uvođenje SOS linije, zabrana otkrivanja identiteta žrtve i nasilnika. Poseban značaj predstavlja pooštavanje kazne zbog kršenja zaštitnih mjera koja sada može rezultirati zatvorskom kaznom do tri godine, pri čemu otkup kazne novčanom uplatom nije moguć.

Ključne riječi: Zakon o zaštiti od nasilja u porodici i nasilja nad ženama u Federaciji Bosne i Hercegovine, mjere zaštite, žrtve nasilja, sankcije prema počiniocu nasilja.

UVOD

Nasilje u porodici u Bosni i Hercegovini kao jedan od najvećih izazova bosansko-hercegovačkog društva nanosi brojne posljedice, kako ženi žrtvi i porodici te društvu u cjelini.

Kao društvo Bosna i Hercegovina je postala visokotolerantna na skoro sve oblike nasilja i negativnih pojava povezanim sa nasiljem, te je tako i nasilje u porodici nažalost postalo naša svakodnevica. Svakodnevno vidimo naslove u bosanskohercegovačkim medijima koji govore o užasnim primjerima nasilja u porodici koji nerijetko rezultiraju i smrtnim ishodom, a takođe su česti izvještaji nevladinih organizacija koji iznose podatke o primjerima nasilja u porodici kroz istraživanje ili se bave pomoći žrtvama nasilja u porodici (Mušić, 2018, str. 169).

Društvo mora u velikoj mjeri govoriti o postojanju nasilja u porodici i treba što više pažnje posvetiti samoj prevenciji da do takvog nasilja ne dođe (Nalo, 2020, str. 50).

Sam Porodični zakon Federacije Bosne i Hercegovine u osnovnim odredbama zabranjuje u porodici nasilničko ponašanje bračnog/vanbračnog partnera te bilo kojeg drugog člana porodice, narušavanjem fizičkog i psihičkog integriteta osobe žrtve nasilja (čl. 4 PZ FBiH).

U okviru realizacije Strategije za prevenciju i borbu protiv nasilja u porodici 2024-2027. (Službene novine Federacije BiH, broj 100/23), usvojen je Zakon o zaštiti od nasilja u porodici i nasilja nad ženama u FBiH (Službene novine FBiH broj 19/25), u daljem tekstu: ZZNP. Ovim Zakonom se u zakonodavstvo djelimično preuzima Direktiva (EU) 2024/1385 Evropskog parlamenta i Vijeća od 14. maja 2024. godine o suzbijanju nasilja prema ženama i nasilja u porodici (SL L2024/1385), kao i preporuke Komiteta potpisnica Istanbulske konvencije (čl. 2 Zakona).

Frndić Imamović, M. i Pustahija, A. (2025). Uvođenje strožijih mjera zaštite žrtava i strožijih sankcija za počiniocje nasilja u porodici u svjetlu novog Zakona o zaštiti od nasilja u porodici i nasilja nad ženama u Federaciji Bosne i Hercegovine. *STED Conference 14(2)*, 169-176.

Godinama se upućivalo na inicijative za donošenje zakona koji bi kroz veće mjere zaštite žrtve nasilja, ali i posebne mjere procjene rizika policijskih organa, spašavao živote žena od nasilja i njegove eskalacije.

Zakon će u velikoj mjeri pomoći da se prevenira eskalacija nasilja nad žrtvom, time što je predviđen veliki broj izmjena koje su fokusirane na preventivni rad i multisektoralnu saradnju institucija subjekata zaštite, koja je svih ovih godina nedostajala.

Institucije u Bosni i Hercegovini su godinama pojedinačno radile u najboljoj namjeri sve što su mogle, ali je zbog nedostatka ovakve saradnje dolazilo, ne samo do eskalacije nasilja, nego i loše kaznene politike, zbog čega se tražilo pooštavanje kazni za počiniocje nasilja.

Zaštita od nasilja je efikasnija i uspješnija ukoliko su država, njeni nadležni organi i tijela, spremni i sposobni djelovati, kako preventivno tako i represivno (Traljić i Bubić, 2007, str. 151).

U ovom radu pokušat ćemo ukratko prikazati nasilje i oblike nasilja u porodici, pokušati saznati koja je uloga u preventivnom i kurativnom djelovanju institucija kad su u pitanju žrtve nasilja i subjekti zaštite, te kao porodično nasilje tretira pravna legislative naše države, bazirajući se na novi Zakon o zaštiti od nasilja u porodici i nasilja nad ženama u FBiH.

MEĐUNARODNI I DOMAĆI PRAVNI OKVIR ZA SPRJEČAVANJE I SUZBIJANJE NASILJA U PORODICI

Međunarodne norme i smjernice za sprječavanje i suzbijanje nasilja u porodici su prisutne na tri nivoa: Ujedinjeni narodi (UN), Vijeće Evrope (VE) i Evropska unija (EU).

Kad su u pitanju Ujedinjeni narodi, oblast nasilja u porodici regulisana je slijedećim dokumentima: Univerzalna deklaracija o ljudskim pravima, Konvencija o ukidanju svih oblika diskriminacije nad ženama CEDAW, Bečka i Pekinška deklaracija, Rezolucija vijeća sigurnosti UN 1325 - Žene, mir i sigurnost, Konvencija o političkim pravima žena, Konvencija o državljanstvu udatih žena.

Na nivou Vijeća Evrope imamo: Evropska konvencija o zaštiti ljudskih prava i osnovnih sloboda i njeni protokoli, Evropska socijalna povelja, Deklaracija o ravnopravnosti između žena i muškaraca, Konvencija o prevenciji i sprečavanju nasilja nad ženama i nasilja u porodici (Istanbulska konvencija), Deklaracija o politici suprotstavljanja nasilju nad ženama.

Na nivou Evropske unije najvažni dokumenti koji regulišu oblast nasilja u porodici su: Konvencija o sprečavanju i borbi protiv nasilja nad ženama i nasilja u porodici, Amsterdamski sporazum Evropske unije, Povelja o osnovnim pravima Evropske unije, Direktive EU o jednakoj plaći, jednakom tretmanu, socijalnom osiguranju, roditeljskom odsustvu, Rezolucija Evropskog parlamenta o nasilju nad ženama, Rezolucija Evropskog parlamenta o potrebi ustanovljavanja kampanje širom EU za nultu toleranciju prema nasilju nad ženama.

Domaće norme i smjernice u Bosni i Hercegovini, regulisane su na državnom i entitetskom nivou. Na državnom nivou imamo Ustav BiH, Zakon o ravnopravnosti spolova (Službeni glasnik BiH broj 32/10) i Zakon o zabrani diskriminacije (Službeni glasnik BiH, broj 59/09 i 66/16). Kad je u pitanju Federacija Bosne i Hercegovine, ovu oblast regulišu slijedeći propisi: Ustav FBiH (Član II A. 2. i Amandman V) i Ustavi kantona u FBiH, Krivični zakon FBiH (Službene novine FBiH, broj 36/03, 37/03, 21/04, 69/04, 18/05, 42/10, 42/11, 59/14, 76/14, 46/16 i 75/17), Porodični zakon FBiH (Službene novine FBiH, broj 35/05, 41/05 i 31/14, Zakon o zaštiti od nasilja u porodici i nasilja nad ženama u FBiH (Službene novine FBiH broj 19/25), Zakon o ustanovama socijalne zaštite FBiH (Službene novine FBiH, broj 64/22) i Zakon o osnovama socijalne zaštite, zaštite civilnih žrtava rata i zaštite porodice sa djecom FBiH (Službene novine FBiH, broj 36/99, 54/04, 39/06, 14/09, 45/16 i 40/18) i Strategija za prevenciju i borbu protiv nasilja u porodici 2024-2027.

Može se konstatovati da je domaći pravni okvir dosta sveobuhvatno i kvalitetno uređen, u nekim dijelovima postoje interna preklapanja ili neusklađenosti sa evropskim pravnim sistemima, ali dosljedna primjena postojećih zakonskih rješenja nudi dovoljno pravnih instrumenata za uspješnu zaštitu žrtava nasilja. Međutim, stvarna primjena pravnih aspekata zaštite od nasilja u porodici u Bosni i Hercegovini je nešto što u praksi izgleda dosta diskutabilnije (Mušić, 2018, str. 180).

Pustahija, A., et al. (2025). Uvođenje strožijih mjera zaštite žrtava i strožijih sankcija za počiniocce nasilja u porodici u svjetlu novog Zakona o zaštiti od nasilja u porodici i nasilja nad ženama u Federaciji Bosne i Hercegovine. *STED Conference 14(2)*, 169-176.

STRATEGIJA ZA PREVENCIJU I BORBU PROTIV NASILJA U PORODICI 2024-2027.

Strategija za prevenciju i borbu protiv nasilja u porodici 2024-2027. povezana je sa Strategijom razvoja Federacije Bosne i Hercegovine 2021-2027., koja će promovisati toleranciju, nenasilje i rodnu ravnopravnost u porodici i društvu direktno, ali i u okviru drugih prioriteta i mjera indirektno. Također, Strategijom se realiziraju i obaveze prema Konvenciji Vijeća Evrope o sprječavanju i borbi protiv nasilja nad ženama i nasilja u porodici – Istanbulska konvencija, koju je Bosna i Hercegovina ratificirala i kao država preuzela obavezu da osigura uslove za sprječavanje nasilja, provođenje istrage, kažnjavanje počinioca nasilja i osiguranje uslova za reparaciju žrtvama nasilja (Strategija za prevenciju i borbu protiv nasilja u porodici 2024-2027, str. 6)

Bosna i Hercegovina je samim tim preuzela i odgovornost za nepostupanje u slučajevima nasilja nad ženama i nasilja u porodici, ukoliko kao država ne osigura uslove za implementaciju obaveza preuzetih iz Konvencije. Važan dokument u ovoj oblasti je i Konvencija o eliminaciji svih oblika diskriminacije žena - CEDAW koja predstavlja međunarodnopravni instrument u borbi protiv diskriminacije na osnovu spola. Konvencija je sastavni dio Ustava Bosne i Hercegovine (Aneks I), čime se primjenjuje direktno i ima prioritet nad državnim zakonima.

Strategija predstavlja važan dokument i u dostizanju ciljeva održivog razvoja u Bosni i Hercegovini, a posebno Podcilja 16.1:” Značajno smanjiti sve oblike nasilja i s njima povezane stope smrtnih slučajeva”.

Bosna i Hercegovina se ujedno, sa 192 države članice Ujedinjenih nacija, obavezala da će provesti Agendu 2030 za održivi razvoj, koja se sastoji od 17 ciljeva i 169 podciljeva. Također, u Bosni i Hercegovini je 2021. godine Vijeće ministara Bosne i Hercegovine zajedno sa entitetskim vladama i vladom Brčko distrikta, usvojilo Okvir za realizaciju Ciljeva održivog razvoja u BiH kojim su globalni Ciljevi održivog razvoja prilagođeni lokalnom kontekstu. Okvirom se promovira i princip „Niko ne smije biti izostavljen “koji ima za cilj da ranjive kategorije društva budu prepoznate i uključe se u sve politike. Upravo se ovom strategijom fokusira na jednu specifičnu kategoriju stanovništva koja se susreće sa nasiljem u porodici, čime Federacija Bosne i Hercegovine daje značajan doprinos implementaciji Okvira i Ciljeva održivog razvoja (Strategija za prevenciju i borbu protiv nasilja u porodici 2024-2027, str. 6).

POJAM I OBLICI NASILJA U PORODICI I SUBJEKTI PRAVA NA ZAŠTITU OD NASILJA

Nasilje u porodici označava svako djelo fizičkog, seksualnog, psihičkog odnosno ekonomskog nasilja do kojeg dođe u porodici ili domaćinstvu ili između bivših ili sadašnjih bračnih ili vanbračnih partnera, neovisno od toga da li učinilac dijeli ili je dijelio domaćinstvo sa žrtvom. Nasilje prema ženama označava kršenje ljudskih prava i oblik diskriminacije nad ženama i predstavlja sva djela rodno zasnovanog nasilja koja dovode do, odnosno mogu dovesti do fizičke, seksualne, psihičke odnosno ekonomske povrede odnosno patnje za žene, obuhvatajući i prijetnje takvim djelima, prinudu odnosno protivpravno lišavanje slobode, bilo u javnosti ili u privatnom životu (član 8. stav 1 i 2. ZZNP).

S obzirom na navedeno, oblici nasilja u porodici su:

- fizičko nasilje,
- psihičko nasilje,
- seksualno nasilje,
- ekonomsko nasilje i
- drugi oblici nasilja.

Fizičko nasilje podrazumijeva primjenu fizičke sile ili psihičke prinude na fizički ili psihički integritet, fizički napad, bez obzira da li je nastupila fizička povreda ili nije, svako postupanje koje može prouzrokovati ili izazvati opsnost da će prouzrokovati psihičku ili fizičku bol, prouzokovanje straha ili lične ugroženosti ili povredu dostojanstva ucjenom ili drugom prinudom (Traljić i Bubić, 2007, str. 153).

Frndić Imamović, M. i Pustahija, A. (2025). Uvođenje strožijih mjera zaštite žrtava i strožijih sankcija za počinioc nasilja u porodici u svjetlu novog Zakona o zaštiti od nasilja u porodici i nasilja nad ženama u Federaciji Bosne i Hercegovine. *STED Conference 14(2)*, 169-176.

Psihičko nasilje predstavlja primjenu psihičke prinude na psihički integritet, verbalni napad, vrijeđanje, psovanje, nazivanje pogrđnim imenima, te drugi načini grubog uznemiravanja i uhođenja.

Seksualno nasilje predstavlja seksualno uznemiravanje i uznemiravanje u skladu sa Zakonom o ravnopravnosti spolova u BiH.

Ekonomsko nasilje predstavlja oštećenje ili uništenje zajedničke imovine ili imovine u posjedu ili pokušaj da se to učini, svako postupanje koje može prouzrokovati ili izazvati opasnost da će prouzrokovati ekonomsku štetu (Ganija H., 2016, str. 47).

Drugi oblici nasilja predstavljaju propuštanje dužne pažnje nadzora ili nepružanje pomoći i zaštite članu porodice, iako za to postoji moralna i zakonska obaveza.

Bez obzira koji od oblika nasilja se dešava i kojem članu porodice, nasilje u porodici strukturalno doprinosi disfunkcionalnosti porodice, a posebno doprinosi razvijanju poremećaja u ponašanju kod djece. Ukoliko djeca od najranije dobi naviknu da budu posmatrači nasilja ili žrtve nasilja, to u dosta slučajeva implicira predispoziciju djece da u kasnijem periodu života postanu zlostavljači, a samim time postanu dio "začaranog kruga" nasilja (Mušić, 2018, str. 170).

Neophodno je razlučiti uzroke nasilja, ali ni u kojem slučaju ne smijemo dozvoliti da se nasilje opravdava sa određenom situacijom ili uzrokom jer za nasilje opravdanja nema, te to moramo kontinuirano naglašavati. Iako se nasilna ponašanja često pokušavaju objasniti uticajima negativnih socioloških faktora, kao što su nezaposlenost, uticaji okruženja, siromaštvo, socijalna isključenost, loša socioekonomska situacija, međutim ne može se izbjeći činjenica da je veliki procenat zlostavljača upravo bio žrtva nasilja u porodici u djetinjstvu.

Kad su u pitanju subjekti koji uživaju pravo na zaštitu od nasilja, novi Zakon (čl. 11 stav 1, 2 i 3.) propisuje da je žrtva nasilja u porodici svaki član porodice ili domaćinstva, koji je izložen radnjama nasilja u porodici, djeteta ako je bilo prisutno prilikom vršenja nasilja prema drugom članu porodice, iako radnje nasilja nisu preduzete prema njemu, te svaka žena izložena radnjama nasilja.

ZAŠTITA ŽENE I OSTALIH ŽRTAVA NASILJA U PORODICI KROZ NOVI ZAKON O ZAŠTITI OD NASILJA U PORODICI I NASILJA NAD ŽENAMA – NOVINE ZAKONA

Kako je i ranije navedeno u ovom radu, novim Zakonom **proširena je definicija ko se sve smatra žrtvom nasilja u porodici**. Dakle, povećava se zaštita samih žrtava, osigurava se da i žene koje nisu dio bračne/vanbračne zajednice budu prepoznate i zaštićene, da djeca ako borave u prostoriji tokom čina nasilja budu također prepoznata kao žrtve nasilja. Ovo rješenje posljedica je činjenice da se nasilničko ponašanje ne javlja samo za vrijeme trajanja braka ili vanbračne zajednice, već i nakon njihovog prestanka. U posljednje vrijeme, svjedoci smo većine slučajeva nasilja nad ženama i djecom čije su zajednice, bračne ili vanbračne, prestale da postoje.

Novim Zakonom uveliko je unaprijeđena i poboljšana uloga i saradnja između subjekata zaštite. Kad su u pitanju **subjekti zaštite**, zaštitu, pomoć i podršku žrtvama nasilja dužni su pružiti svi nadležni organi: **policijski organi, tužilaštva, sudovi, organi starateljstva, zdravstvene i obrazovne ustanove, zavodi za besplatnu pravnu pomoć i druge javne ustanove, te specijalizirane nevladine organizacije** koje pružaju usluge stručne podrške i savjetovanja, te usluge institucionalnog socijalnog zbrinjavanja i socijalne podrške koje imaju za cilj zaštitu i prevenciju od nasilja.

Rješavanje ovih predmeta se zasniva na načelu hitnosti, tako da su svi navedeni subjekti dužni učiniti sve da žrtve nasilja imaju pravo na brz pristup svim subjektima zaštite i oslobođene su plaćanja svih troškova postupka (čl. 13. stav 1, 2, 3 i 4. Zakona). Nevladine organizacije imaju višegodišnje iskustvo u podizanju svijesti javnosti o problemima nasilja, pružanja pomoći žrtvama i njihovom zbrinjavanju, te predstavljaju značajan resurs koji institucije treba da prepoznaju, strateški iskoriste i naprave konkretne planove za saradnju (Mušić, 2018, str. 188.).

Novi Zakon izazovan je najviše za organe starateljstva odnosno centre za socijalni rad s obzirom na to da se sada bave i pravom počinioca nasilja u porodici kao roditelja u kontekstu viđanja sa djetetom, što je do sada bilo u nadležnosti sudova.

Pustahija, A., et al. (2025). Uvođenje strožijih mjera zaštite žrtava i strožijih sankcija za počiniocce nasilja u porodici u svjetlu novog Zakona o zaštiti od nasilja u porodici i nasilja nad ženama u Federaciji Bosne i Hercegovine. *STED Conference 14(2)*, 169-176.

Posebna pažnja usmjerena je na samu **hitnost postupka i obavezu postupanja subjekata zaštite** koji su dužni odmah prijaviti i osigurati hitno rješavanje predmeta nasilja, vodeći računa da su interes i dobrobit žrtve prioritet u tim postupcima, a naročito ako je žrtva dijete, osoba starija od 65 godina, osoba s invaliditetom i osoba pod starateljstvom. Niti jedan od subjekata zaštite – ni policija, ni sudovi, ni organi starateljstva, ni ustanove ne mogu same postići očekivane rezultate. Dakle, dužni su međusobno sarađivati, sarađivati i sa drugim nadležnim vladinim tijelima i organima i nevladinim organizacijama u najboljem interesu žrtve, kao i razmjenjivati potrebne podatke i informacije (čl. 19. stav 1 i 2. Zakona).

Zaposleni u subjektima zaštite, obrazovnim, socijalnim i zdravstvenim ustanovama dužni su odmah prijaviti policijskom organu ili tužilaštvu djelo nasilja o kojem su obaviješteni ili o kojem saznaju na neki drugi način.

Kad je u pitanju sam **postupak nakon prijema prijave da je učinjeno nasilje**, organ kome je podnesena prijava dužan je bez odlaganja o tome obavijestiti organ starateljstva, koji će odmah pružiti socijalnu zaštitu i psihosocijalnu pomoć žrtvi, preduzeti druge mjere iz svoje nadležnosti, te o tome sačiniti službeni izvještaj kojeg bez odlaganja dostavlja nadležnom policijskom organu. Zdravstvena ustanova obaviti će besplatan ljekarski pregled radi utvrđivanja i evidentiranja postojanja povreda fizičkog ili psihičkog integriteta i pružiti žrtvi nasilja potrebnu ljekarsku pomoć (čl. 20. stav 4 i 5. Zakona).

O izvršenom nasilju nadležni policijski organ odmah obavještava i nadležno tužilaštvo i uz izvještaj dostavlja prikupljene dokaze i procjenu rizika. Policijski organ dužan je o procjeni rizika bez odlaganja obavijestiti organ starateljstva. Nadležni tužilac, u pisanoj formi, obavještava nadležni policijski organ, žrtvu nasilja i organ starateljstva o podizanju optužnice protiv osumnjičene osobe, o neprovođenju istrage ili obustavi istrage, kao i o razlozima za neprovođenje i obustavu istrage. Na zahtjev organa starateljstva ili na zahtjev policijskog organa ili na zahtjev žrtve, sigurne kuće dužne su osigurati smještaj žrtvi nasilja (čl. 20. stav 6, 7, 8 i 9. Zakona).

Poseban značaj predstavlja **uvodenje mjere policijske procjene rizika za sve žrtve nasilja**, naročito rizika od smrtnosti, ozbiljnosti situacije i rizika od ponavljanja nasilja s ciljem upravljanja rizikom i koordiniranog osiguranja zaštite i podrške žrtvama nasilja, naročito da li počinioci djela nasilja posjeduju vatreno oružje, odnosno imaju pristup vatrenom oružju te o potrebi njegovog privremenog oduzimanja (vidjeti detaljnije čl. 21. stav 3. Zakona). Iako je novi Zakon dobar i značajno doprinosi zaštiti žena i djece od nasilja u porodici, još uvijek postoji sumnja i strah u njegovu primjenu, naročito u pogledu ove procjene rizika. Za primjenu Zakona će trebati vremena i edukacije, kako bi se u skladu sa kapacitetima policijskih službenika moglo najbolje i najefikasnije pomoći žrtvama nasilja.

Ovim Zakonom se proširuju i **hitne mjere zaštite** poput udaljavanja iz stana i kuće i zabrana vraćanja, zabrana približavanja žrtvi i djeci, zabrana komunikacije, uznemiravanja i uhođenja. Svrha im je otklanjanje neposredne opasnosti za žrtve nasilja i njihovu djecu, kao i sprečavanje ponavljanja nasilja (čl. 23. stav 1. Zakona).

Nadležni policijski organ će, kada su za to ispunjeni zakonom propisani uslovi, odmah pismeno narediti jednu ili više hitnih mjera zaštite o čemu je dužan obavijestiti nadležnog tužioca (zahtjev za određivanje hitnih mjera nadležnom policijskom organu mogu podnijeti i nadležni tužilac, žrtva ili organ starateljstva). Policijski organ je dužan o njima odlučiti u roku od šest sati od sata prijema zahtjeva (čl. 24. stav 1, 2, 3, 4 i 5. Zakona).

Osoba prema kojoj su mjere određene, za vrijeme trajanja mjera, ima pravo podnijeti pritužbu nadležnom tužilaštvu, koji je o pritužbi dužan odlučiti u roku od 12 sati od podnošenja pritužbe. Hitne mjere zaštite na osnovu naredbe policijskog organa stupaju na snagu odmah i mogu trajati najduže 48 sati, o čemu nadležni policijski organ bez odgađanja obavještava žrtvu nasilja i organ starateljstva.

Poseban značaj se pridaje **zaštitnim mjerama** čija je svrha otklanjanje opasnosti po fizički i psihički integritet žrtve nasilja i sprečavanje ponavljanja nasilja otklanjanjem stanja i uslova koji mogu uticati ili poticajno djelovati da učinilac ponovno izvrši radnje nasilja (udaljenje iz stana, kuće ili drugog stambenog prostora i zabrana vraćanja u stan, kuću ili drugi stambeni prostor (vidjeti više čl. 27. Zakona), zabrana približavanja žrtvi nasilja i prema potrebi djeci žrtve (vidjeti

Frndić Imamović, M. i Pustahija, A. (2025). Uvođenje strožijih mjera zaštite žrtava i strožijih sankcija za počinioc nasilja u porodici u svjetlu novog Zakona o zaštiti od nasilja u porodici i nasilja nad ženama u Federaciji Bosne i Hercegovine. *STED Conference 14(2)*, 169-176. više čl. 28. Zakona), zabrana komunikacije, uznemiravanja i uhođenja žrtve nasilja (vidjeti više čl. 29. Zakona), obavezan psihosocijalni tretman (vidjeti više čl. 30. Zakona), obavezno liječenje od ovisnosti (vidjeti više čl. 31. Zakona) i privremeno lišenje slobode i zadržavanje (vidjeti više čl. 32. Zakona).

Velika prednost i novina ovog Zakona je uvođenje elektronskog praćenja poštivanja prve dvije zaštitne mjere putem tzv. **elektronski nadzor nasilnika**. Zakonom je predviđeno uvođenje elektronske narukvice nasilniku sa izrečenim mjerama zabrane prilaska, kako bi policija mogla pratiti da li ih poštuje i na vrijeme pomoći žrtvi ukoliko pokuša prekršiti mjeru. U slučaju da se nasilnik približi žrtvi, ona će dobiti upozorenje da se sakrije, a najbliža policija alarm da krene prema njoj i spriječi njegovo približavanje, dok će počinitelj biti kažnjen za kršenje mjera. Sve ove zaštitne mjere ne mogu trajati duže od 3 godine.

Osim toga, Zakonom su sigurne kuće prepoznate kao sudionici sistema u zbrinjavanju i pomaganju žrtvama u trajanju od najduže 6 mjeseci, pa se sada, osim nevladinih organizacija, sigurne kuće mogu osnovati i kao javne ustanove, odnosno finansirati iz budžeta, što bi moglo ojačati njihovu finansijsku stabilnost i dugoročnost (čl. 65. Zakona).

Najkontraverzniji član Zakona je član 67. o zabrani javnog objavljivanja podataka o žrtvi ili počiniocu nasilja (naglasak je na identitetu počinioca nasilja) na osnovu koje se može utvrditi identitet žrtve ili člana porodice žrtve, osim ako je punoljetna žrtva s tim izričito saglasna. Zakon, dakle, ne propisuje izuzetke za slučajeve kada je objavljivanje podataka o počiniocu u javnom interesu. Umjesto da imamo registar počinitelja porodičnog nasilja, ovakvim zakonskim rješenjima ih skrivamo od javnosti. Objavljivanje identiteta nasilnika može imati preventivno dejstvo, omogućiti njegov brži pronalazak i spriječiti ponavljanje zločina nad istom ili nekom novom žrtvom. Što hitnije bi se prebalo inicirati uvođenje izuzetaka kada bi objavljivanje identiteta počinioca nasilja bilo u javnom interesu.

Kada su u pitanju ostali oblici zaštite, Zakon dalje propisuje da bi Ministarstvo rada i socijalne politike FBiH, uz podršku Ministarstva saobraćaja i komunikacija, trebalo osigurati uspostavljanje 24-satne besplatne SOS telefonske linije koja pokriva cijelu Federaciju BiH, radi davanja savjeta i pružanja podrške žrtvama nasilja (čl. 71. Zakona). Podrška žrtvama putem besplatnih SOS linija postoji i na teritoriji RS-a.

Pozvati SOS telefon osim žrtava, obavezni su pozvati i drugi građani, kako bi prijavili nasilje u svom okruženju. Na taj način, mogu se brzo i efikasno dobiti informacije i savjeti od stručnih osoba o načinu pružanja pomoći ženama i djeci koji su žrtve nasilja (Nalo, 2020, str. 33).

Jedna od najvažnijih izmjena Zakona predstavlja **zabrana otkupa kazne zatvora od godinu dana nasilnicima zbog kršenja hitnih i zaštitnih mjera**. Nasilnici koji budu osuđeni na kaznu zatvora do godinu dana, zbog bilo kojeg oblika online nasilja ili u javnom prostoru, neće moći otkupiti kaznu zatvora, kao što je slučaj u drugim krivičnim djelima, a što najviše nailazilo na kritiku stručne javnosti. Novčanom kaznom u iznosu od 1.000,00 do 5.000,00 KM kaznit će se osoba koja prekrši zaštitne mjere obaveznog psihosocijalnog tretmana i liječenja od ovisnosti.

ZAKLJUČCI

Problem nasilja nad ženama je u stalnom porastu, te kao takav zahtijeva zajednički rad države i svih nadležnih organa te daljnja istraživanja ovog problema. Nepružanju adekvatne zaštite doprinose nekad i same žene žrtve nasilja, prvenstveno jer su nedovoljno educirane i neinformisane, pa ne znaju kome treba prvo da se obrate radi pružanja preventivne zaštite i na koji način se mogu zaštititi od nasilničkog ponašanja ukoliko su ga doživjele. Također, nemogućnost samostalnog osiguranja vlastite egzistencije, nada da će nasilje u budućnosti prestati, te strah od intenziviranja nasilničkog ponašanja zbog prijave i vođenja postupka protiv nasilnika, samo su još neki od razloga zašto žrtve ne prijavljuju pretrpljeno nasilje. Dakle, u budućnosti je potrebno sistemski raditi na edukaciji i podizanju svijesti kod žena da slobodnije prijavljuju nasilje i sarađuju sa subjektima zaštite te potraže pomoć.

Neophodno je razlučiti uzroke nasilja, ali ni u kojem slučaju ne smijemo dozvoliti da se nasilje opravdava sa određenom situacijom ili uzrokom jer za nasilje opravdanja nema. Iako se nasilna ponašanja često pokušavaju objasniti uticajima negativnih socioloških faktora, kao što su

Pustahija, A., et al. (2025). Uvođenje strožijih mjera zaštite žrtava i strožijih sankcija za počinioc nasilja u porodici u svjetlu novog Zakona o zaštiti od nasilja u porodici i nasilja nad ženama u Federaciji Bosne i Hercegovine. *STED Conference 14(2)*, 169-176.

nezaposlenost, uticaji okruženja, siromaštvo, socijalna isključenost, loša socioekonomska situacija, međutim ne može se izbjeći činjenica da je veliki procenat zlostavljača upravo bio žrtva nasilja u porodici u djetinjstvu.

Skoro polovina žena u Bosni i Hercegovini je iskusila neki oblik nasilja od svoje petnaeste godine, pokazalo je istraživanje OSCE-a o nasilju nad ženama u BiH. Prema podacima Visokog sudskog i tužilačkog vijeća, za nasilje nad ženama najčešće su se izricale uslovne, a manje zatvorske i novčane kazne.

Dakle, donošenje novog Zakona o zaštiti od nasilja u porodici i nasilja nad ženama u FBiH predstavlja samo početak u poboljšanju usluga zaštite i podrške osobama koje su doživjele nasilje.

Za razliku od prijašnjeg zakona, ovaj novi Zakon predstavlja sveobuhvatan mehanizam zaštite i borbe protiv nasilja kroz hitne i zaštitne mjere koje podrazumijevaju udaljenje osobe iz prostora, odnosno stana, zabranu uhođenja, približavanja, koje izriče policijski organ pismeno (traju 48 sati), te mjera lišenje slobode prilikom izricanja hitnih mjera.

Uvodi se procjena rizika za sve žrtve nasilja, poput provjeravanja rizika od smrtnosti (provjera ponašanja osobe koja vrši nasilje: da li posjeduje vatreno oružje, da li je ranije počinio nasilje u porodici ili drugi vid nasilja, da li je prijetio ubistvom, te da li je mentalno oboljela osoba).

Novi Zakon o zaštiti od nasilja u porodici i zaštiti žena od nasilja u Federaciji BiH prilagođen je Istanbulskoj konvenciji, predviđa više novca za sigurne kuće iz budžeta, sistem tzv. elektronske narukvice za praćenje, koji bi pokazivao lokaciju učinilaca ovih krivičnih djela, kao i strožije kazne za nasilnike.

Aдекватnu primjenu ovog Zakona trebale bi pratiti i izmjene Krivičnog zakona, na čije se stavljanje na dnevni red i glasanje čeka već duže vrijeme, a koji bi uveo kažnjavanje nasilja i u online prostoru. Krivična djela nasilja u porodici su regulirana krivičnim zakonima entiteta Federacija BiH, Republika Srpska i Brčko distrikta. Za djela za koja prijeti zatvorska kazna do deset godina sude opštinski sudovi. Pred deset kantonalnih sudova te pet okružnih sudova u Republici Srpskoj procesuiraju se krivična djela gdje je zapriječena zatvorska kazna duža od deset godina, gdje spadaju ubistva. Kada je u pitanju Federacija Bosne i Hercegovine, vlast još uvijek nije našla najefikasnije rješenje kako spriječiti ili barem ublažiti eskalaciju nasilja nad najosjetljivijim članovima porodice, ženama i djecom.

Međutim, novim Zakonom u velikoj mjeri je poboljšana saradnja institucija nadležnih za postupanje u slučajevima prijave nasilja: kako efikasno ostvariti kontakte i brzo razmijeniti informacije, obavijestiti jedni druge o sumnji na prisustvo nasilja ili o prisustvu nasilja, hitno intervenisati u slučaju prijave nasilja, sarađivati na pružanju podrške i pomoći žrtvama nasilja, ramjenjivati informacije i mišljenja tokom rehabilitacije žrtve te toku provođenja hitnih i zaštitnih mjera izrečenih počiniocu nasilja. Strategija za prevenciju i borbu protiv nasilja u porodici 2024. – 2027. i Zakon o zaštiti od nasilja u porodici i nasilja nad ženama FBiH predstavljaju veliki napredak u usklađivanju domaćih politika rada sa međunarodnim standardima te u poboljšanju usluga zaštite i podrške osobama koje su doživjele nasilje.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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INTRODUCING STRICTER PROTECTIVE MEASURES FOR VICTIMS AND HARSHER PENALTIES FOR PERPETRATORS OF DOMESTIC VIOLENCE IN LIGHT OF THE NEW LAW ON PROTECTION FROM DOMESTIC VIOLENCE AND VIOLENCE AGAINST WOMEN IN THE FEDERATION OF BOSNIA AND HERZEGOVINA

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ABSTRACT

The House of Peoples of the Parliament of the Federation of Bosnia and Herzegovina, at its session held on March 4, 2025, unanimously adopted the Law on Protection from Domestic Violence and Violence Against Women, thereby introducing stricter protective measures for victims and harsher penalties for perpetrators of violence within the territory of the Federation of Bosnia and Herzegovina. Compared to the previous law, the new legal provisions impose greater responsibility and provide a broader scope of action for all those involved in the decision-making chain in the fight against domestic violence (police, judicial authorities, social work centers, and educational institutions). This paper will provide a detailed explanation of the innovations introduced by the Law: the expanded definition of a victim, electronic monitoring of offenders, sanctioning of online violence, establishment of an SOS hotline, prohibition of disclosing the identities of victims and perpetrators. Particular significance is given to the tightening of penalties for violating protective measures, which can now result in a prison sentence of up to three years, with no possibility of converting the sentence into a monetary fine.

Keywords: Law on Protection from Domestic Violence and Violence Against Women in the Federation of Bosnia and Herzegovina, protective measures, victims of violence, penalties for perpetrators of violence.

HUMAN DIGNITY AS PART OF THE MATERIAE CONSTITUTIONIS

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ABSTRACT

Over time, the content of the *materiae constitutionis* has not changed significantly, so even in the oldest constitutional texts, we can find provisions regarding the organization of power, a catalog of constitutional rights and freedoms, and finally, provisions about constitutional amendments. However, in the period after the Second World War, an indispensable part of the *materiae constitutionis* became those provisions that relate to the constitutional recognition and guarantee of human dignity as one of the core principles of the constitutional order. In this paper, the author will, through a comparative analysis, attempt to determine how constitutions increasingly include provisions on human dignity in their texts. Finally, special attention will be given to the role such provisions play within modern constitutional orders.

Keywords: constitution, *materiae constitutionis*, human dignity.

INTRODUCTION

In this paper, the author will present which provisions can today be considered as an inseparable part of the *materiae constitutionis*. The analysis will begin with the classic components of *materiae constitutionis* that can be found in the earliest written constitutions from the late 18th century, which have remained in constitutional texts up to the present day. First, the focus is on provisions related to organizational constitutional rules that structure state bodies and assign them the powers to resolve matters within their constitutional jurisdiction. Furthermore, since the first modern constitutions, constitutional texts also include provisions that guarantee fundamental rights and freedoms to the citizens of the state. Lastly, as the third component of classical *materiae constitutionis*, constitutions, from the very beginnings of modern written constitutionalism, also contain provisions regulating the procedure for constitutional amendments.

These three groups of rules: organizational rules, charters of fundamental rights and freedoms, and provisions on constitutional amendments - make up the classical part of *materiae constitutionis*, because all of these rules can be found in the vast majority of constitutions created since the early days of written constitutionality in the late 18th century, including the first written constitutions of the United States (1789) and the French Constitution (1791). The aforementioned parts of *materiae constitutionis* will be discussed in the first part of this paper through a comparative and historical analysis. However, the author will pay particular attention to the emergence of provisions related to human dignity and the constitutional guarantees for its protection, which began to appear in written constitutions after the end of World War II in 1945 and are now found in the vast majority of constitutions. In this way, the concept of human dignity, although present in philosophical and theological considerations since ancient times, only more recently became part of *materiae constitutionis*. The second part of the paper will analyze the reception of the concept of human dignity in constitutional texts after 1945 and its relationship with other parts of *materiae constitutionis*. In this analysis, both the content of the constitutional texts themselves and various viewpoints from comparative literature on the incorporation of human dignity into constitutions will be taken into account.

CLASSIC CONTENT OF *MATERIAE CONSTITUTIONIS*

When discussing the content of a constitution, it is important to start with the fact that, according to one of the many definitions of a constitution, it is: "A written act of the highest legal force that primarily regulates the foundations, but not all foundations, and not only the foundations of a given state and social order" (Bačić 2017:28). Based on this definition, it is easy to distinguish that the content of a constitution is not always precisely defined. For this reason, constitutions vary in terms of the scope of their text. On one hand, there is the example of the U.S. Constitution, which is extremely short, containing only 4,543 words, while on the other hand, there is the extraordinarily extensive Indian Constitution, which contains 183,175 words. However, over time, it has become customary for constitutions to include certain elements that are now considered an essential part of *materiae constitutionis*. The following section of this chapter will show which provisions, from the very beginnings of written constitutionality in the late 18th century (some even earlier!), have been considered an indispensable part of every constitution.

ORGANIZATIONAL RULES

First, we can state that every constitution primarily contains organizational rules that determine the competence of state bodies established by the constitution and also define the very form of the state (Bačić 2021:31). When speaking about these organizational provisions, we must bear in mind that this is precisely the point where we say that every state has a constitution in the material sense. In other words, every state has certain rules according to which the state's governance is organized, regardless of whether these rules are codified and written in a single document or are scattered across multiple legal documents, or simply applied and become unquestionable as constitutional customs over time (Bačić 2017:27-28). Therefore, authors emphasize that, in this sense, every state has had a constitution in the material sense, from antiquity to the present day. This is why we should not be surprised that Aristotle already distinguished between a constitution as a set of rules defining the functioning and organization of the state, and laws. According to him, *Politeia* was the foundation upon which the entire state organization was built, where rules regarding the purpose and competence of state bodies could be found. On the other hand, *Nomoi* were laws based on these foundations that further regulated the exercise of power by state bodies. (Aristotle 1916: 147).

CHARTERS OF FUNDAMENTAL RIGHTS AND FREEDOMS

The second fundamental part of *materiae constitutionis* concerns the regulation of relations between state bodies and citizens. Here, it is primarily about prescribing certain fundamental rights and freedoms guaranteed to all citizens by the constitution itself. Since the very beginnings of written constitutionality, it became customary to include catalogues of rights and freedoms in constitutional documents. The oldest written constitution in the world, the U.S. Constitution, adopted in 1787 and entering into force in 1789, did not initially contain a catalogue of rights and freedoms. However, the founding fathers quickly recognized the importance of guaranteeing rights and freedoms through the constitution, so just two years after the constitution's adoption, it was amended with the first ten amendments that specifically contained the fundamental rights and freedoms guaranteed by the constitution. These first ten amendments to the U.S. Constitution, known as the Bill of Rights, became a model for future constitutions. Since then, it has become customary for drafters to include provisions regarding the protection and guarantee of fundamental rights and freedoms in constitutional texts. Moreover, these provisions are often considered so important that they are typically placed right at the beginning of the constitution, after introductory provisions, and almost always before provisions related to the organization of state power. Examples of this can certainly be found in the Constitution of the Republic of Croatia and the Constitution of Bosnia and Herzegovina.

The link between a constitution as a set of organizational rules regulating the existence and competence of state bodies and a catalogue of citizens' rights and freedoms that must be respected by the state is perhaps best demonstrated in understanding the constitution as a fundamental provision and a set of principles preventing arbitrary exercise of power (Sartori 1962: 855). Thus,

constitutions become, on the one hand, an effective mechanism for the functioning of state power, while, on the other hand, they ensure that such power is not exercised arbitrarily but is limited through the separation of powers into legislative, judicial, and executive branches. At the same time, it is also limited by the existence of constitutionally guaranteed rights and freedoms that must be respected by all, including state bodies. This understanding of the constitution as a means to limit state power and prevent arbitrary exercise of power by state bodies is supported by numerous authors, including F. Hayek (Trajkovska-Hristovska 2019: 44). Ultimately, in modern democratic constitutions, organizational constitutional provisions primarily serve to enable the normal functioning of state bodies while ensuring that state power and its holders are not arbitrary but limited in the exercise of their powers. They are limited by the principle of separation of powers, which is divided horizontally into legislative, executive, and judicial branches, vertically into state power and the power of lower organizational units (e.g., local and regional authorities), and, finally, by a temporal limitation, as in democracies, all holders of state power are elected for a specific term, after which citizens are given the right to elect new holders of particular state offices. However, it is important to emphasize that the existence of constitutionally prescribed fundamental rights and freedoms, along with the binding requirement for their respect by all, especially state bodies, is an extremely important element in limiting state power and preventing arbitrary rule.

CLAUSES ON CONSTITUTIONAL AMENDMENTS AS PART OF *MATERIAE CONSTITUTIONIS*

The third important part of *materiae constitutionis* consists of clauses on constitutional amendments, which set the rules for changing the constitution itself. Provisions on constitutional amendments can be found in the earliest written constitutions, including the U.S. Constitution, the oldest written constitution in the world (Article V of the U.S. Constitution). Although there were differing views among the founding fathers regarding the need to include a procedure for amendments within the constitution itself, the thoughts of T. Jefferson ultimately prevailed. He believed that constitutional amendments must be possible and that each generation must be guaranteed the ability to independently decide on the foundations of social order as outlined in the constitution, as everything "except inalienable human rights" (Posavec 1994: 74) should be subject to change and adaptation to the new circumstances of time. (Roznai 2017: 189) G. Mason shared a similar view, arguing that the constitution should foresee the possibility of change, as constitutional amendments would be needed in the future, and it was better to provide a procedure for peaceful amendments, as otherwise there would be a risk of changes occurring through violent methods (Farrand 1911: 202-203). Ultimately, the U.S. Constitution incorporated Article V, which provides for a complex and demanding procedure for constitutional amendments. Amendment clauses can also be found in some of the oldest European constitutions, such as the Polish Constitution of 1791 (Article VI) and the French Constitution of 1791 (Section VII).

The practice of establishing rules for constitutional amendments became widespread over time, and today, almost every written constitution contains provisions regulating procedures for its amendment. In this sense, it can be said that amendment clauses are an indispensable part of *materiae constitutionis*. The importance of these provisions is recognized not only in constitutional practice but also in constitutional law theory. For example, one of the constitutional classics, A.V. Dicey, stated at the end of the 19th century that the issue of constitutional amendments was one of the central themes of constitutional law (Dicey 1895: 388), and similar views can be found in other older authors such as J. Burgess, who describes provisions on amendments as "the most important parts of the constitution" (Burgess 1902: 137). For K. Lowenstein, provisions on constitutional amendments, along with provisions on the separation of powers and guarantees of rights and freedoms, form one of the fundamental elements of a political constitution (Trajkovska-Hristovska 2019: 44). Finally, the importance of provisions on constitutional amendments is also emphasized by modern authors, such as R. Albert, who refers to amendment clauses as "gatekeepers" of the constitutional text (Albert 2014: 913-914).

Provisions on the possibility of constitutional change are closely linked to the principle of popular sovereignty as a fundamental postulate in organizing a constitutional democratic order.

According to D. Lutz, the principle of popular sovereignty was the guiding idea for the founding fathers when they decided to include provisions for constitutional change in Article V at the Constitutional Convention in Philadelphia. If supreme power lies in the hands of the people as the sovereign, it is entirely understandable that the people have the right to adopt a new constitution but also to change the existing constitutional order (Lutz 1995: 238-239). In this way, provisions on constitutional amendments are connected to fundamental human rights because the right to change the constitution, either through direct decision or via elected representatives, in accordance with the theory of popular sovereignty, is one of the inalienable rights of the people as the sovereign. Furthermore, the constitution often also provides for the power of state bodies to carry out the process of constitutional change. Thus, when discussing organizational rules that determine the competence of state bodies, this also includes a special power, constitutionally established, to carry out the process of constitutional amendment. Of course, it should be noted that only the people, as sovereign, always and exclusively possess the pre-constitutional constituent power (*fr. pouvoir constituant*), which establishes the constitutional order and from which all other constituted powers (*fr. pouvoir constitué*) arise, including the power to amend the constitution, which, unlike the constituent power, is always subordinate to the constitution itself (Zlatić 2021: 27-29).

HUMAN DIGNITY AS A PART OF *MATERIAE CONSTITUTIONIS*

The concept of human dignity today is inseparably linked to constitutional-democratic systems based on the rule of law. However, although human dignity has been present in philosophical and theological discussions since ancient times, it only started appearing in constitutions after the end of World War II. This chapter will explore in more detail when and how the concept of human dignity was incorporated into constitutional documents, and will then examine the relationship between human dignity and other fundamental parts of *materiae constitutionis*.

THE EMERGENCE OF HUMAN DIGNITY IN CONSTITUTIONAL TEXTS

Before the end of World War II, the concept of human dignity rarely appeared in constitutional texts. According to research by D. Shulztiner and G. Carmi, only five constitutions adopted before 1945 contained provisions related to the concept of human dignity. These were: the Mexican Constitution of 1917, the German Constitution of 1919, the Finnish Constitution of 1919, the Irish Constitution of 1922, and the Cuban Constitution of 1940 (Shulztiner, Carmi 2014: 464). However, after World War II, constitution-makers, surely guided by the horrific experiences of the war, began incorporating provisions that guarantee and protect human dignity as an inseparable part of human existence. M. Mahlmann, for example, notes that the concept of human dignity became the central part of the "normative project of human rights" and "civilized constitutionalism after 1945," and thus an essential element of almost all constitutional systems after World War II (Mahlmann 2010: 10). The trend of including human dignity in constitutions continued in the decades following World War II. According to the previously mentioned research by D. Shulztiner and G. Carmi from 2012, 80% of constitutions now contain provisions on human dignity.

Human dignity is incorporated into constitutional texts in various ways and can be found in different parts of the constitutional text. Some constitutions include human dignity in their introductory and fundamental provisions as one of the central principles of the entire constitutional system. For example, in Germany's Basic Law (German: *Grundgesetz*), Article 1 states that human dignity is inviolable and that it is the duty of the state and public authorities to protect it (Article 1, *Grundgesetz*). Finally, according to Article 79, Paragraph 3 of the *Grundgesetz*, the provision in Article 1 on human dignity represents an unamendable part of the German constitution, meaning that human dignity, as one of the central principles of the German constitutional order, cannot be changed even by constitutional amendments. As Hofmann and Hesse emphasize, human dignity represents the normative foundation of the Federal Republic of Germany (*Dreier 2014: 376*). Many other constitution-makers follow the German example and highlight human dignity as one of the core principles of their constitutional order, including it either in the fundamental constitutional

provisions (e.g., constitutions of Brazil, South Africa, Portugal, etc.) or mentioning it in the preambles (e.g., constitutions of Poland, Ireland, Czech Republic, etc.). The concept of human dignity is also found in the provisions of the Croatian Constitution, which in Article 35 guarantees the respect and protection of dignity, and in the Constitution of Bosnia and Herzegovina, whose preamble mentions dignity as one of the foundations of the constitutional order.

In addition to the general definition of human dignity as one of the core postulates of the constitutional order, many constitutions specify it by linking it to the protection and realization of other fundamental rights or goals intended to be achieved by the establishment of the constitutional system. In such cases, human dignity serves as a guideline for the application of constitutional norms, indicating how state authorities should act in specific situations. A common example of this is, as noted by D. Shulztiner and G. Carmi, the legal deprivation of individual freedom, which prescribes that detained or arrested persons should be treated in a way that respects their dignity. Such constitutional provisions can be found in Finland, Armenia, Nicaragua, and Croatia (Shulztiner, Carmi 2014: 477). Human dignity is also frequently used as a foundational principle when regulating constitutional rights related to labor, with an emphasis on preserving the dignity of workers and ensuring appropriate working conditions and compensation, as found in the constitutions of Portugal, Angola, Colombia, Argentina, and South Korea (Shulztiner, Carmi 2014: 477-478). Other constitutions prescribe the general obligation of the state to ensure adequate material conditions for a dignified life for all individuals, especially those belonging to vulnerable groups (children, the elderly, persons with disabilities, etc.), as seen in the constitutions of Switzerland, Finland, Bolivia, and Serbia (Shulztiner, Carmi 2014: 478-480).

THE RELATIONSHIP BETWEEN HUMAN DIGNITY AND OTHER PARTS OF *MATERIAE CONSTITUTIONIS*

Given everything previously mentioned, it can be concluded that, over the last 80 years, human dignity has become an indispensable element of *materiae constitutionis*. Furthermore, this concept has become one of the core principles of constitutional orders worldwide and is closely interwoven with other parts of *materiae constitutionis*. When discussing the connection between human dignity and fundamental rights, we should consider the definition accepted by many authors, including P. Bačić, according to which human rights are "universal legal guarantees that protect individuals and groups against actions that infringe on fundamental freedoms and human dignity" (P. Bačić 2007:13), and accordingly, "human rights are part of the inherent dignity and value of the human person" (P. Bačić 2007:13). It is clear that the concept of human dignity forms the basis for all other human rights. Therefore, human dignity is a *conditio sine qua non* for all human rights, as without its preservation, it is impossible to talk about the existence of fundamental human rights, since all human rights have their source in human dignity itself. Ultimately, any constitutional system that aims to ensure effective protection of fundamental rights and freedoms must have human dignity as a foundational value (Brownsword 2014: 1, 13), and thus, it can be said that human dignity is the core of what is recognized and defined in theory as Western constitutionalism based on the rule of law (Baer 2009: 435).

When discussing the relationship between human dignity and other parts of *materiae constitutionis*, we must also consider that the requirement to preserve and protect human dignity forms a fundamental demand for the action of all state bodies, both in the performance of their regular functions and when exercising their powers within the process of constitutional amendment. We have already mentioned that provisions on human dignity in constitutional texts first serve to position human dignity as one of the core principles of a given constitutional order. In this sense, state bodies are initially required not to do anything in the exercise of their regular powers that could endanger the dignity of individuals. However, on the other hand, these same bodies are also expected to actively work toward promoting and protecting human dignity in the exercise of their constitutional powers, which is particularly evident in those constitutional provisions that, as we have already shown, link human dignity to the realization of other rights or values of the constitutional order (the right to decent working conditions, wages, or ensuring material conditions for a dignified life).

Furthermore, state authorities are also required to safeguard human dignity during constitutional amendments. In this process, the protection of human dignity must not be jeopardized. Indeed, some constitutions explicitly prohibit changes to parts of the constitution related to constitutional guarantees of human dignity. The most well-known example of this is the provision of Article 79, Paragraph 3 of the German *Grundgesetz*, which explicitly prohibits changes to, among other things, the provisions of the *Grundgesetz* that pertain to human dignity. However, it is our belief that, given that human dignity represents the very foundation of the constitutional order (Zlatić 2022: 33-48), even in constitutional systems that do not explicitly prohibit the amendment of certain parts of the constitution, such limitations on the power of constituted authorities to amend the constitution are implicitly assumed, and they are obliged to adhere to them. An example can be found in the Croatian Constitution (Kostadinov 2011: 320, Omejec 2015: 28, Horvat-Vuković 2015: 488-492). Otherwise, they would undermine the very foundations of the existing constitutional order and thereby exceed the constitutional powers granted to them, which consist of amending the existing constitution, not destroying it or replacing it with a new one. Moreover, human dignity as an inseparable part of human existence limits even the sovereign in the exercise of constituent power in the process of adopting a new constitution. Although constituent power cannot be limited by legal rules, including constitutional ones (since it precedes them), those holding constituent power cannot exercise it in a way that would endanger human dignity, as this would negate the very idea of constituent power, which necessarily implies the creation of a new constitutional order by a community of equal individuals gathered in a people who are sovereign (Friedrich 1950: 135, Kalyvas 2005: 235, Colón Ríos 2012: 117-118, Zlatić 2022: 43-47).

CONCLUSIONS

The constitution, as the fundamental legal act of any democratic society, has always had the task of regulating the essential aspects of political and social life. Analyzing historical and comparative sources, it is evident that from the very beginnings of modern constitutionality at the end of the 18th century, written constitutions have contained certain sections that became inseparable elements of every constitution, or the classical parts of *materiae constitutionis*. These sections include: organizational rules establishing the structure of state authority, charters on fundamental rights and freedoms protecting individuals from arbitrary actions by the authorities, and provisions on constitutional amendments that ensure flexibility and adaptability.

However, what represents a significant turning point regarding *materiae constitutionis* is the ubiquitous and growing role of human dignity in constitutional texts after World War II. The experiences of war, totalitarianism, and systemic violations of human rights prompted constitution-makers to place human dignity at the center of their constitutional systems as a fundamental value. The German Basic Law (*Grundgesetz*) of 1949, with its provision on the inviolability of human dignity, set a normative precedent followed by many other constitutions around the world.

It is important to emphasize and understand that human dignity is not merely an additional element, it now stands at the core of constitutional architecture, permeating all other parts of *materiae constitutionis*. As shown in the paper, fundamental rights have their source in human dignity; the organizational structure of power must act in a manner that respects and promotes the dignity of citizens, and even the possibility of constitutional amendments must align with the preservation of dignity as an inalienable value. In this sense, it can be concluded that human dignity has definitively become a new, fourth, inseparable, and substantial part of *materiae constitutionis*. Its inclusion in constitutional texts does not only represent a reaction to historical traumas but also an affirmation of the idea that the legal order, if it is to be just and sustainable, must be founded on the respect for every human being as an autonomous and equal member of the community. Ultimately, a modern constitutional order, without the explicit recognition and protection of human dignity, can hardly achieve the purpose of the rule of law, democracy, and fundamental human rights. This confirms that human dignity does not merely become a part of the constitutional text but also represents the ontological foundation of the entire constitutional order that strives for the realization of the ideals of the rule of law.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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IT SECTION
IT SEKCIJA

„OČI ŠIROM OTVORENE” – JEDAN OD POSTULATA INFORMACIONE SIGURNOSTI

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SAŽETAK

Ovaj rad predstavlja originalni naučni doprinos kroz sveobuhvatnu primjenu metodologije studije slučaja u analizi evoluirajućih cyber prijetnji koje oblikuju informacionu sigurnost u 21. vijeku. Umjesto deskriptivnog ili preglednog pristupa, rad uvodi jasnu naučnu strukturu, definisane kriterijume odabira studija slučaja, metodološki okvir i transverzalnu analizu između različitih tipova napada. Cilj je pružiti dublji uvid u obrazac ponašanja modernih napadača, identifikovati kritične ranjivosti i formulisati preporuke koje se mogu praktično primijeniti u organizacijama svih veličina. Rad uključuje četiri proširene studije slučaja, zasnovane na kombinaciji naučne literature, industrijskih izvještaja i aktuelnih izvora.

Ključne riječi: informaciona sigurnost, sajber napadi, prijetnje, malver, praktični primjeri

UVOD

Digitalna transformacija i globalna povezanost donijele su bez presedana nivo zavisnosti od informacionih sistema. Međutim, ova zavisnost stvorila je i novu vrstu ranjivosti – sisteme koji su istovremeno kompleksni, distribuirani i kontinuirano izloženi sofisticiranim napadima. Tradicionalni modeli zaštite zasnovani na perimetarskoj sigurnosti više nisu dovoljni. Prema izvještaju ENISA-e (2024), broj napada koji uključuju lanac snabdijevanja porastao je za 68%, dok je broj napada koji iskorištavaju zero-day ranjivosti porastao za 45% u posljednje tri godine.

Iako se u literaturi često sreću radovi koji opisuju pojedinačne incidente, mali broj njih uspostavlja jasnu metodologiju koja omogućava poređenje, generalizaciju i dublje razumijevanje. Ovaj rad zato uvodi case-study pristup, koji omogućava strukturisanu i naučno validnu analizu kompleksnih cyber incidenata. Kroz analizu četiri reprezentativna slučaja, rad daje sveobuhvatnu sliku trendova, alata i tehnika koje oblikuju savremeni cyber prostor.

METODOLOGIJA

Metodologija studije slučaja korištena u ovom radu zasniva se na principima Roberta Yina (2014), jednog od najznačajnijih autora u ovoj oblasti. Primijenjeni su sljedeći koraci:

- Definisanje cilja istraživanja – identifikovati obrasce ponašanja modernih napada, njihove efekte i dominantne ranjivosti koje su eksploatisane u organizacijama.
- Kriterijumi za izbor slučajeva: raznovrsnost tipova napada (ransomware, ICS napad, supply-chain, napad na maloprodajni sektor), međunarodni uticaj i značaj, pouzdani izvori koji omogućavaju rekonstrukciju napada.
- Izvori podataka – korišteni su zvanični izvještaji ENISA, CISA, CrowdStrike, Microsoft Threat Intelligence, akademske studije, te relevantni novinski članci.

Kamiš, A. i sar. (2025). "Oči širom otvorene" – jedan od rezultata informacione sigurnosti. *STED Conference 14(2)*, 187-192.

- Analitički okvir – svaki slučaj je analiziran prema četiri kriterijuma: (1) vektor napada, (2) ranjivosti, (3) efekti napada, (4) naučene lekcije.
- Usporedna analiza slučajeva – identifikovani su zajednički obrasci i specifične razlike, što je poslužilo za formulisanje zaključaka i preporuka.

Primjena ove metodologije omogućila je dubinsku analizu incidenata uz visok nivo naučne pouzdanosti.

NAPADI, UPADI I MALVER – NEVIDLJIVE PRIJETNJE DIGITALNOG SVIJETA

U savremenom digitalnom okruženju, informaciona sigurnost suočava se sa sve sofisticiranijim prijetnjama koje dolaze iz raznih izvora – od pojedinaca sa osnovnim tehničkim znanjem do dobro organizovanih kriminalnih grupa ili čak državnih aktera. Među najčešćim i najopasnijim oblicima ugrožavanja informacione sigurnosti nalaze se napadi, neovlašćeni upadi u sisteme i maliciozni softver, poznat kao malver. Razumijevanje ovih prijetnji ključno je za razvijanje efikasnih strategija zaštite i jačanje otpornosti informacionih sistema.

Napadi: Ciljani i masovni pristupi kompromitovanju sistema

Napad na informacioni sistem predstavlja svaku radnju čiji je cilj ugrožavanje povjerljivosti, integriteta ili dostupnosti podataka. Ovi napadi mogu biti ciljani, kada napadač želi kompromitovati konkretan sistem, organizaciju ili osobu, ili masovni, gdje napadač nasumično napada veliki broj sistema u nadi da će pronaći ranjivosti.

Jedan od najraširenijih oblika je DoS (Denial of Service) i njegov sofisticiraniji oblik DDoS (Distributed Denial of Service). Ovi napadi imaju za cilj preopterećenje resursa sistema kako bi onemogućili pristup legitimnim korisnicima. Posebno su opasni za organizacije koje zavise od dostupnosti svojih usluga u realnom vremenu, poput banaka, e-trgovine i zdravstvenih ustanova.

Brute-force su napadi pri kojim napadač pokušava da pogodi lozinku ili enkripcijski ključ isprobavanjem velikog broja kombinacija. Phishing su napadi u kojim se korisnici socijalnim inženjeringom navode da otkriju povjerljive informacije, a spadaju u svakodnevne izazove bezbjednosnih timova. Razvoj generativnih AI alata dodatno komplikuje odbranu, jer lažne poruke i web-stranice izgledaju autentičnije nego ikada.

Upadi: Dan kad napadač uđe u sistem

Neovlašćeni upad podrazumijeva pristup informacijama ili sistemima bez dozvole. On može biti rezultat ranjivosti u softveru, neadekvatne konfiguracije mrežnih uređaja, loših lozinki ili krađe legitimnih pristupnih podataka.

Napadači koji uspiju ostvariti pristup često ne ostaju pasivni. Umjesto toga, oni mogu:

- eksfiltrirati podatke,
- instalirati backdoor za kasniji ponovni ulazak,
- širiti se lateralno unutar mreže u potrazi za dodatnim osjetljivim informacijama ili boljim pozicijama ili
- šifrovati podatke s ciljem iznude (ransomware).

Upadi su često teško uočljivi jer napadači koriste tehnike prikrivanja poput enkripcije komunikacije, tunelovanja kroz dozvoljene servise (npr. DNS ili HTTPS) i manipulacije logovima. Detekcija takvih aktivnosti zahtijeva napredne SIEM (Security Information and Event Management) alate i pažljivo osmišljene politike nadzora i reagovanja.

Malver: Nevidljivi napadač unutar sistema

Maliciozni softver, poznat kao malver, predstavlja jednu od najefikasnijih metoda za kompromitovanje sistema. Razlikujemo više vrsta malvera, u zavisnosti od funkcionalnosti:

- Virus – samoreplicirajući kod koji se vezuje za druge fajlove ili programe i aktivira se kada se oni pokrenu.

Kamiš, A. i sar. (2025). “Oči širom otvorene” – jedan od rezultata informacione sigurnosti. *STED Conference 14(2)*, 187-192.

- Trojanac (Trojan) – maskira se kao legitimni program, ali u pozadini obavlja zlonamjerne aktivnosti.
- Ransomware – šifrira podatke korisnika i traži otkupninu za dešifrovanje.
- Spyware – tajno prikuplja informacije o korisniku bez njegovog znanja.
- Rootkit – omogućava napadaču administratorski pristup i često je nevidljiv konvencionalnim metodama detekcije.

Distribucija malvera može se odvijati putem e-mail priloga, malicioznih web-stranica, kompromitovanih softverskih paketa ili preko USB uređaja. Jedan od ključnih izazova u borbi protiv malvera je njegova sposobnost da se neprestano mijenja, koristeći tehnike poput polimorfizma i metamorfizma kako bi izbjegao antivirusne sisteme.

TRENDovi INFORMACIONE SIGURNOSTI U 2025. GODINI

Kako digitalno poslovanje i tehnologija nastavljaju ubrzano da se razvijaju, tako i prijetnje po informacionu sigurnost postaju sve kompleksnije, dinamičnije i teže predvidive. Godina 2025. donosi niz sigurnosnih izazova i trendova koji značajno utiču na strategije zaštite podataka i infrastrukture u privatnom i javnom sektoru. U nastavku se ističe šest ključnih trendova koji obilježavaju informacionu bezbjednost u 2025. godini.

Vještačka inteligencija kao okosnica moderne cyber sigurnosti

Ipak, vještačka inteligencija nije isključivo prijetnja – ona istovremeno postaje stub moderne odbrane. Savremeni sistemi za detekciju prijetnji koriste mašinsko učenje i analitiku ponašanja korisnika (UEBA) kako bi u realnom vremenu prepoznali anomalije koje mogu ukazivati na upad. AI takođe omogućava bržu analizu incidenata, automatsko reagovanje (SOAR sistemi) i predikciju potencijalnih rizika. Budućnost informacione sigurnosti oslanjaće se na simbiotski odnos između čovjeka i mašine, gdje AI pruža skalabilnost i brzinu, a ljudi kontekstualno razumijevanje i donošenje odluka.

Balansiranje između sigurnosti i korisničkog iskustva

Rast svijesti o bezbjednosti često dolazi u konflikt sa potrebom za jednostavnim i fluidnim korisničkim iskustvom. Korisnici žele brz pristup podacima i servisima, s minimalnim brojem prepreka, dok sigurnosni timovi insistiraju na višefaktorskoj autentifikaciji, segmentaciji mreže i strožim pravilima pristupa. U 2025. godini fokus se pomjera ka “security by design” pristupu, gdje se sigurnost ugrađuje u rješenja bez narušavanja korisničkog komfora. Primjeri uključuju biometrijsku autentifikaciju, behavioral passwordless pristup i kontekstualno upravljanje pristupom.

Sigurnost u oblaku i rizik od pogrešne konfiguracije

Migracija u cloud je nezaustavljiva, ali s njom dolaze i novi sigurnosni izazovi. Najveći među njima u 2025. godini ostaje pogrešna konfiguracija servisa u oblaku, koja često omogućava neovlašćeni pristup podacima. Zbog složenosti cloud okruženja (više dobavljača, mikrosruga, kontejneri), čak i male greške u podešavanjima mogu imati ozbiljne posljedice. Edukacija DevOps timova, implementacija Infrastructure-as-Code pristupa sa sigurnosnim politikama i kontinuirani cloud security posture management (CSPM) alati postaju nezaobilazan dio modernog sigurnosnog arsenala.

PROŠIRENE STUDIJE SLUČAJA

Studija slučaja 1: Stuxnet (2010) – Prvo digitalno oružje

Stuxnet predstavlja najpoznatiji primjer cyber oružja kreiranog s ciljem sabotiranja industrijskih procesa. Napad je kompromitovao SCADA sisteme i PLC kontrolere u iranskim nuklearnim postrojenjima.

- Vektor napada: četiri zero-day ranjivosti u Windows OS-u i fizički unašanje USB uređaja.
- Ranjivosti: nedostatak segmentacije ICS mreže, mogućnost manipulacije PLC logikom.

Kamiš, A. i sar. (2025). "Oči širom otvorene" – jedan od rezultata informacione sigurnosti. *STED Conference 14*(2), 187-192.

- Posljedice: uništenje postrojenja i značajno usporavanje nuklearnog programa Irana; globalni šok u industriji.
- Naučene lekcije: važnost air-gap politika, verifikacije firmware integriteta i forenzičkog nadzora ICS-a.

Kao što ističe Langner (2013), Stuxnet je promijenio shvatanje cyber sigurnosti u industriji jer je pokazao da digitalni napad može izazvati fizičku destrukciju.

Studija slučaja 2: WannaCry (2017) – Globalni ransomware talas

WannaCry je bio jedan od najbrže širećih ransomware incidenata. Iskoristio je SMB ranjivost EternalBlue koju je NSA godinama koristila, a kasnije je procurela u javnost.

- Vektor napada: exploit EternalBlue (CVE-2017-0144).
- Ranjivosti: neprimijenjeni sigurnosni patchovi i zastarjeli sistemi.
- Posljedice: više od 230.000 kompromitovanih računara u 150 država.
- Najpogođeniji sektor: britanske zdravstvene ustanove (NHS).

Prema Microsoft Security Report (2018), čak 98% pogođenih sistema bilo je bez zakrpe starije od dva mjeseca.

Studija slučaja 3: SolarWinds (2020) – Supply-chain napad

SolarWinds napad je paradigma modernih supply-chain prijetnji. Napadači, pripisani APT29 grupi, uspjeli su kompromitovati build proces kompanije SolarWinds i ubaciti zlonamjerni kod u legitimno ažuriranje.

- Vektor napada: kompromitovana CI/CD infrastruktura.
- Ranjivosti: nedovoljno kontrolisan pristup kod signing sertifikatima.
- Posljedice: kompromitacija više od 18.000 organizacija, uključujući američke vladine institucije.
- Naučene lekcije: važnost zero-trust modela i verifikacije integriteta build procesa.
- Sinha & Bernroider (2022) navode da je SolarWinds najkompleksniji supply-chain napad u istoriji.

Studija slučaja 4: Marks & Spencer (2025) – Napad na maloprodajni sektor

Napad grupe Scattered Spider na britanski lanac Marks & Spencer pokazao je ranjivost maloprodajnog sektora, posebno u pogledu third-party integracija.

- Vektor napada: kompromitacija partnerske firme i krađa pristupnih podataka.
- Ranjivosti: slab nadzor eksternih dobavljača i zastarjeli IAM sistemi.
- Posljedice: prekid online prodaje, krađa ličnih podataka i procijenjena šteta od 300 miliona funti.

Izveštaj The Times (2025) navodi da će operativni poremećaji od ovog napada trajati mjesecima.

ZAKLJUČCI

Uporedna analiza četiri studije slučaja pokazala je da savremeni cyber napadi, bez obzira na kontekst ili ciljnu organizaciju, dijele niz strukturnih i operativnih sličnosti. U svim analiziranim incidentima ključnu ulogu imala je eksploatacija ranjivosti koje nisu bile pravovremeno zakrpljene, što potvrđuje da neadekvatan patch menadžment i dalje predstavlja jednu od najkritičnijih slabih tačaka u informacionim sistemima. Napadači su se, osim toga, oslanjali na zloupotrebu legitimnih administrativnih alata, čime su uspijevali izbjeći detekciju i zadržati dugotrajan pristup kompromitovanim okruženjima. Uočen je i visok stepen tehničke i organizacione sofisticiranosti, uključujući napredne tehnike prikrivanja tragova, upotrebu modularne maliciozne infrastrukture i koordinirano djelovanje unutar dobro strukturiranih kriminalnih grupa.

Kamiš, A. i sar. (2025). "Oči širom otvorene" – jedan od rezultata informacione sigurnosti. *STED Conference 14(2)*, 187-192.

Posebno značajan nalaz odnosi se na supply-chain napade, koji se potvrđuju kao jedna od najvećih prijetnji modernim organizacijama. Njihova sposobnost da kompromituju širi ekosistem kroz jednog dobavljača čini ih izuzetno opasnim i teško detektabilnim. Istovremeno, ransomware ostaje najrasprostranjeniji oblik napada s direktnim i mjerljivim uticajem na kontinuitet poslovanja, što ga i dalje svrstava u prioritete izazove za sve vrste organizacija.

Rezultati istraživanja ukazuju na to da odgovor na savremene cyber prijetnje zahtijeva holistički i proaktivan pristup. Ključne preporuke obuhvataju implementaciju zero-trust arhitekture, ubrzanje procesa zakrpa, primjenu višefaktorske autentifikacije, kontinuirani nadzor anomalija putem UEBA i SIEM sistema, unapređenje sigurnosnih kontrola kod eksternih partnera, te primjenu naprednih i redovno testiranih strategija backup-a i oporavka.

Ovaj rad potvrđuje da strukturiran case-study pristup omogućava dublje razumijevanje obrazaca savremenih napada i pruža čvrstu osnovu za definisanje praktičnih i primjenjivih sigurnosnih preporuka. Dobijeni uvidi mogu značajno doprinijeti unapređenju sigurnosnih politika i jačanju otpornosti organizacija u realnom poslovnom okruženju.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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"EYES WIDE OPEN" – ONE OF THE FUNDAMENTALS OF INFORMATION SECURITY

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ABSTRACT

This paper presents an original scientific contribution through the comprehensive application of the case study methodology in analyzing the evolving cyber threats that shape information security in the 21st century. Rather than relying on a descriptive or review-based approach, the paper introduces a clear scientific structure with defined criteria for selecting case studies, a methodological framework, and a transversal analysis across different types of attacks. The objective is to provide deeper insight into the behavioral patterns of modern threat actors, identify critical vulnerabilities, and formulate recommendations that can be practically applied within organizations of all sizes. The paper includes four extended case studies based on a combination of academic literature, industry reports, and contemporary sources.

Keywords: information security, cyberattacks, threats, malware, practical examples.

REVOLUTIONIZING SUPPLY CHAINS: THE TRANSFORMATIVE ROLE OF ARTIFICIAL INTELLIGENCE IN LOGISTICS

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ABSTRACT

Artificial Intelligence (AI) is transforming logistics by significantly improving efficiency and reducing costs across supply chain operations. This review paper investigates AI's impact on logistics through a systematic synthesis of secondary data sourced from professional and industry publications, utilizing Google searches and AI tools such as ChatGPT with keywords including "AI in logistics" and "Logistics Automation." The research focuses on AI-driven optimizations in inventory management, route planning, and warehouse automation, supported by a synthesis of case studies of leading industry adopters. Findings indicate that AI implementation leads to substantial reductions in inventory and transportation costs and significant increases in warehouse productivity. Successful applications also enhance delivery reliability and customer satisfaction, although challenges such as high implementation costs and skill shortages remain. In conclusion, AI is revolutionizing logistics by streamlining operations and promoting sustainability, yet strategic investments are essential to overcome barriers and unlock future advancements like autonomous delivery systems.

Keywords: Artificial Intelligence, Logistics, Supply Chain, Automation, Optimization

INTRODUCTION

The rapid advancement of Artificial Intelligence (AI) has positioned it as a cornerstone of modern logistics, driving innovation across supply chain management. AI's ability to process vast datasets and automate complex tasks enables businesses to optimize operations, reduce costs, and enhance service quality. From autonomous vehicles to predictive analytics, AI is reshaping logistics by addressing inefficiencies and unlocking new opportunities (Mecalux, 2023).

This paper examines AI's impact on logistics through successful case studies and explores its benefits and challenges. The research addresses two key questions:

- How does AI optimize logistics processes, including cost reduction and efficiency improvements?
- What are the most successful examples of AI implementation in logistics, and what are their benefits and challenges?

Data for this study were sourced from Google searches (Google Scholar, etc..) and AI tools like ChatGPT and Gemini, using keywords such as "artificial intelligence in logistics," "AI use cases in logistics," and "benefits and challenges of AI."

MATERIAL AND METHODS OF WORK

This paper is a systematic literature review and synthesis of secondary data collected from professional and industry sources. The primary objective was to identify and structure the key applications, benefits, and challenges of Artificial Intelligence in supply chain management. Information was gathered using Google searches and AI-assisted tools, including ChatGPT and Gemini, with keywords such as “artificial intelligence in logistics,” “AI in supply chain management,” and “logistics automation.” Sources include industry reports, white papers, and corporate and professional publications, primarily from 2018 to 2024. The study analyzes case studies of companies like DHL, Huawei, FedEx, and Amazon to evaluate AI’s impact on logistics processes. The collected data were synthesized to identify and structure the key applications, benefits, and challenges of AI in logistics, providing a comprehensive overview of industrial best practices, and addressing research questions, focusing on AI’s role in optimizing operations and the associated benefits and challenges.

LITERATURE REVIEW

Artificial Intelligence (AI), defined as the development of systems capable of performing tasks requiring human intelligence, such as learning, reasoning, and decision-making, has emerged as a transformative technology across industries (Mecalux, 2023). Coined by John McCarthy in 1956, AI encompasses technologies like machine learning, natural language processing, and robotics, enabling applications from virtual assistants to autonomous systems (Levin, 2024). In logistics, AI is revolutionizing supply chain management by optimizing processes, reducing costs, and enhancing efficiency through data-driven insights and automation (Invoitix, 2023). This section reviews the literature on AI’s applications in logistics, focusing on inventory management, transportation, warehouse automation, demand forecasting, sustainability, and ethical considerations, while highlighting implementation challenges.

AI in Inventory Management

AI significantly enhances inventory management by leveraging predictive analytics to forecast demand with high accuracy. Algorithms analyze historical sales data, seasonal trends, and external factors like market conditions to optimize inventory levels, reducing overstocking and stockouts (Mecalux, 2023). Chopra and Meindl (2016) emphasize that AI-driven inventory systems enable just-in-time stocking, minimizing holding costs while ensuring product availability. Furthermore, AI-powered robots automate tasks such as picking, packing, and sorting in warehouses, improving operational speed and reducing human error (AI Business, 2022). Studies indicate that AI can decrease inventory carrying costs by up to 20% in large-scale operations, making it a critical tool for logistics efficiency (Rushton et al., 2021).

AI in Transportation and Route Optimization

Transportation is a key area where AI delivers substantial benefits. Advanced algorithms process real-time data on traffic, weather, and delivery schedules to determine optimal routes, reducing fuel consumption and delivery times (Invoitix, 2023). Palamar (2024) notes that AI-driven route optimization can lower transportation costs by 10–15% through dynamic adjustments to changing conditions. Additionally, AI automates task allocation and load planning, enhancing fleet utilization and reducing empty miles (TLS, n.d.). Research by Chopra (2021) highlights that AI’s ability to integrate multimodal transport data (e.g., road, rail, air) enables seamless coordination across supply chains, improving overall logistics performance.

AI in Warehouse Automation

Warehouse automation is another domain transformed by AI. AI-powered Warehouse Management Systems (WMS) streamline operations like sorting, picking, and transporting goods, increasing throughput and accuracy (AI Business, 2022). Rushton et al. (2021) report that AI-driven robots can process orders up to three times faster than manual labor, significantly boosting productivity. Moreover, AI enables real-time monitoring of goods flow and inventory, optimizing

Vorina, A. et al. (2025). Revolutionizing supply chains: the transformative role of artificial intelligence in logistics. *STED Conference 14*(2), 193-199.

space utilization and reducing operational bottlenecks (Mecalux, 2023). According to a study by McKinsey (2023), companies adopting AI in warehouses can achieve a 30% reduction in operational costs, underscoring its economic impact.

AI in Demand Forecasting

Accurate demand forecasting is critical for efficient logistics, and AI excels in this area by analyzing complex datasets, including consumer behavior, economic indicators, and historical trends (TIMOCOM, 2020). Palamar (2024) argues that AI's predictive capabilities allow companies to anticipate demand fluctuations, enabling proactive inventory and resource planning. A study by Lee and Lee (2020) found that AI-based forecasting models improve accuracy by 25–40% compared to traditional methods, reducing stockouts and excess inventory. This precision enhances supply chain responsiveness and customer satisfaction, positioning AI as a cornerstone of modern logistics strategies (Chopra, 2021).

AI and Sustainability in Logistics

Sustainability is an emerging focus in logistics, and AI contributes by optimizing resource use and reducing environmental impact. AI-driven route optimization minimizes fuel consumption, lowering carbon emissions, while predictive analytics reduces waste through efficient inventory management (UNITE.AI, 2024). Sarkis et al. (2021) highlight that AI can support green logistics by enabling circular supply chains, where materials are reused or recycled based on predictive models. For example, AI systems can optimize reverse logistics for product returns, reducing environmental footprints (Bowersox et al., 2020). Industry reports suggest that AI adoption in logistics could reduce global logistics-related emissions by 10% by 2030 (McKinsey, 2023).

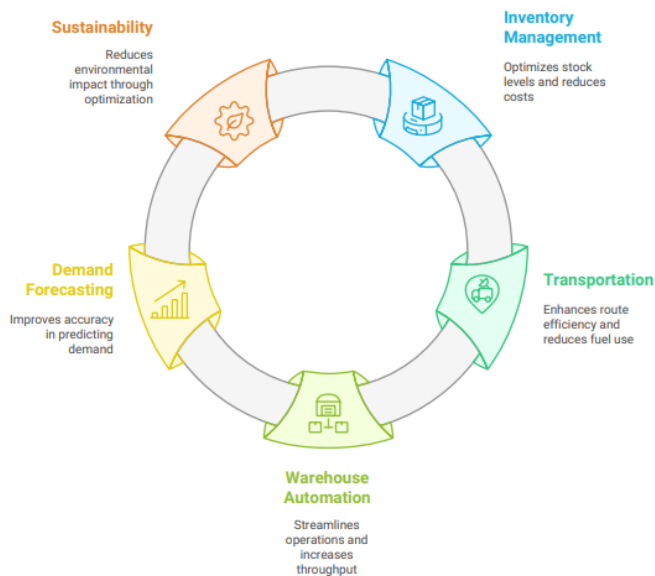


Figure 1. The impact of AI on Logistics.

This figure 1 illustrates how artificial intelligence enhances logistics through five key areas:

- **Inventory Management:** Optimizes stock levels and reduces costs.
- **Transportation:** Increases route efficiency and lowers fuel usage.
- **Warehouse Automation:** Streamlines operations and boosts throughput.
- **Demand Forecasting:** Improves prediction accuracy for demand.
- **Sustainability:** Minimizes environmental impact via optimization.

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Ethical and Social Considerations

Despite its benefits, AI in logistics raises ethical and social concerns. Data privacy is a significant issue, as AI systems rely on large datasets that may include sensitive customer information (DOBA Fakulteta, 2023). Ensuring compliance with regulations like GDPR is critical to maintaining trust (Sarkis et al., 2021). Additionally, AI-driven automation may lead to job displacement, particularly for low-skilled workers, raising concerns about social equity (Finance.si, 2023). Research by Frey and Osborne (2017) estimates that 47% of logistics jobs are at risk of automation, necessitating reskilling programs to mitigate workforce disruption. Ethical AI deployment requires balancing efficiency gains with social responsibility (Lee & Lee, 2020).

Challenges of AI Implementation

Implementing AI in logistics presents several challenges. High initial costs for technology, infrastructure, and training can deter adoption, particularly for small and medium enterprises (Finance.si, 2023). Integration with legacy systems is often complex, requiring significant technical expertise (DOBA Fakulteta, 2023). A shortage of skilled AI professionals further limits implementation, with estimates suggesting a global deficit of millions of data scientists by 2030 (McKinsey, 2023). Cybersecurity risks are also a concern, as AI systems are vulnerable to data breaches (DOBA Fakulteta, 2023). Finally, employee resistance to automation, driven by fears of job loss, can slow adoption, necessitating change management strategies (Finance.si, 2023).

Future Directions

The literature points to a promising future for AI in logistics, with advancements in autonomous delivery systems, smart warehouses, and predictive analytics expected to drive further innovation (UNITE.AI, 2024). AI Business (2021) predicts that by 2030, over 50% of global logistics operations will incorporate AI-driven automation, enhancing efficiency and sustainability. Emerging technologies like blockchain and IoT, combined with AI, are expected to create fully integrated, transparent supply chains (Chopra, 2021). However, addressing implementation challenges, such as cost, skills, and ethics, will be critical to realizing AI's full potential in logistics (Sarkis et al., 2021).

RESULTS: ADDRESSING THE RESEARCH QUESTIONS

Research question 1: How does AI optimize logistics processes, including cost reduction and efficiency improvements?

AI optimizes logistics processes by automating tasks, enhancing decision-making, and leveraging real-time data analytics, leading to significant cost reductions and efficiency improvements. In inventory management, AI employs predictive algorithms to forecast demand, analyzing historical sales, seasonal trends, and market conditions to minimize overstocking and stockouts (Mecalux, 2023).

In transportation, AI optimizes routes by processing real-time data on traffic, weather, and delivery schedules, reducing fuel costs and delivery times by 10–15% (Palamar, 2024). Automated task allocation and load planning further enhance fleet efficiency, minimizing empty miles (TLS, n.d.).

Warehouse automation is another critical area, where AI-powered Warehouse Management Systems (WMS) streamline sorting, picking, and transporting goods. AI-driven robots process orders up to three times faster than manual labor, boosting productivity and reducing operational costs by up to 30% (AI Business, 2022). Real-time monitoring optimizes goods flow, reducing bottlenecks and enhancing space utilization (Mecalux, 2023).

Research question 2: What are the most successful examples of AI implementation in logistics, and what are their benefits and challenges?

Several industry leaders have successfully implemented AI in logistics, showcasing its benefits while navigating significant challenges. DHL employs AI for route optimization and demand forecasting, reducing fuel costs and improving delivery efficiency. This has enhanced

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resource allocation and customer satisfaction, with optimized routes lowering transportation expenses (DHL, 2020). However, DHL faced high initial costs and integration complexities when adopting AI systems (Finance.si, 2023).

Huawei integrates AI to enhance delivery reliability, improving delivery time estimates by 30–80% and boosting efficiency by 30%. This enables better shipment tracking and cost savings, increasing customer trust (Mladipodjetnik.si, 2018). Challenges included a shortage of AI experts and cybersecurity risks associated with handling large datasets (DOBA Fakulteta, 2023).

FedEx uses AI for predictive analytics and delivery optimization, forecasting demand to minimize delays and operational costs. This improves service reliability, with fewer delivery errors (FedEx, 2021). However, employee resistance to automation and the need for extensive training posed implementation hurdles (Finance.si, 2023).

Amazon’s Kiva system, powered by AI, automates warehouse operations using mobile robots, accelerating order processing and reducing costs. AI-driven demand forecasting optimizes inventory, supporting Amazon’s e-commerce growth (Villarreal, 2018). Despite these benefits, Amazon encountered challenges like high infrastructure costs and data privacy concerns, requiring robust cybersecurity measures (DOBA Fakulteta, 2023).

Benefits Across Examples: These cases highlight common benefits, including increased productivity, reduced operational costs (e.g., fuel, storage, labor), improved delivery accuracy, and enhanced customer satisfaction. AI’s automation reduces errors, while predictive analytics and route optimization streamline operations (TLS, 2020; Podjetna Slovenija, 2024).

Challenges Across Examples: Common challenges include high initial investment costs, particularly for technology and training (Finance.si, 2023). Integration with existing systems is complex, often requiring significant technical upgrades (DOBA Fakulteta, 2023).

Future Implications: These examples underscore AI’s potential to transform logistics, but successful implementation requires addressing these challenges through strategic investments, workforce training, and robust data security. The adoption of autonomous delivery systems and smart warehouses, as seen in systems like UPS’s ORION, will further enhance efficiency and sustainability, shaping the future of logistics (UNITE.AI, 2024).



Figure 2. AI in logistics: Balancing benefits and implementation challenges.

The figure 2 shows a flowchart of AI adoption challenges in logistics, progressing from low to high adoption. FedEx faces predictive analytics requiring extensive employee training, DHL deals with route optimization and integration complexities, Huawei addresses delivery reliability and cybersecurity risk management, and Amazon requires warehouse automation with high infrastructure investment. Icons and a color gradient (yellow to pink) illustrate the transition.

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DISCUSSION: BENEFITS AND CHALLENGES OF USAGE AI IN LOGISTICS

Based on the reviewed literature, Table 1 and Table 2 summarize the key benefits and challenges associated with the use of AI in logistics.

Table 1. Benefits of usage AI in logistics.

Benefit	Source
Process Automation – automates tasks like order processing and inventory management, reduces errors, and increases efficiency	TLS, 2020
Route Optimization – calculates optimal routes to minimize transportation costs	Podjetna Slovenija, 2024
Demand Forecasting – provides accurate predictions, reduces storage costs, and improves inventory planning	TIMOCOM, 2020
Warehouse Automation – AI-driven robots enhance speed and accuracy in warehouses	Invoitix, 2023
Customer Satisfaction – personalizes services and improves delivery reliability	TLS, 2020

Table 2. Challenges of usage AI in logistics.

Challenge	Source
High Initial Costs – requires significant investment in technology and training	Finance.si, 2023
Integration Complexities – merging AI with existing systems can be technically challenging	Finance.si, 2023
Skill Shortages – a lack of AI experts hinders adoption	DOBA Fakulteta, 2023
Data Security – handling large datasets increases cybersecurity risks	DOBA Fakulteta, 2023

CONCLUSION

Artificial Intelligence has emerged as a cornerstone of modern logistics, driving automation, optimizing processes, and enabling predictive capabilities that redefine supply chain efficiency. Companies like DHL, Amazon, and Huawei exemplify AI's transformative impact, achieving cost savings, faster deliveries, and improved customer satisfaction. However, challenges such as high initial investments, integration hurdles, and cybersecurity risks must be addressed to fully harness AI's potential.

Looking ahead, AI will continue to revolutionize logistics through autonomous delivery systems, smart warehouses, and advanced demand forecasting. Its ability to adapt to dynamic market conditions positions AI as a critical enabler of sustainable and resilient supply chains. This research highlights AI's dual role as both a disruptor and an innovator, urging businesses to embrace technological advancements while fostering workforce readiness and robust data governance.

This study has several limitations. First, its reliance on qualitative secondary data limits the ability to conduct primary empirical analysis, such as quantitative assessments of AI's impact on specific logistics metrics. The use of Google searches and AI tools like ChatGPT may introduce bias in source selection, potentially overlooking niche or non-digital publications. Second, the focus on large corporations (e.g., DHL, Amazon) may not fully represent the experiences of small and medium enterprises, which face different resource constraints. Third, the study's scope is limited to current AI applications, with less emphasis on emerging technologies like blockchain or IoT, which could further transform logistics. Finally, the lack of longitudinal data restricts insights into the long-term sustainability and scalability of AI implementations.

Future research should address these limitations by incorporating primary data through surveys, interviews, or case studies with logistics firms, particularly smaller enterprises, to capture diverse perspectives. Quantitative studies could measure AI's impact on specific metrics, such as return on investment or carbon footprint reduction, providing more precise insights. Exploring the

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integration of AI with emerging technologies, such as blockchain for transparent supply chains or IoT for real-time tracking, could uncover new optimization opportunities.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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PERFORMANCE COMPARISON OF VARIOUS DATABASE TYPES IN REACT NATIVE APPLICATIONS

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ABSTRACT

In the modern digital age, mobile devices have become an indispensable part of everyday life. With the growing volume of data we handle daily, the speed of data loading and access becomes a crucial factor for the efficient operation of mobile applications. Large datasets are becoming increasingly common, such as, for example, the German collocation dictionary. Given that mobile devices use different operating systems, such as Android and iOS, there is an increasing need for tools that enable the development of cross-platform applications from a single codebase. React Native, as a popular open-source framework, provides exactly this solution. This paper tested the loading of data from the dictionary using React Native applications. This data loading was performed in four ways: using AsyncStorage, SQLite, TinyBase, and Realm databases. A different number of rows was loaded, and the loading speed was compared.

Keywords: Android, database, iOS, performance testing, React Native.

INTRODUCTION

In today's digital age, mobile devices have become an essential part of everyday life. With the growing volume of data handled by mobile applications, performance – especially data loading speed and access time – has become a crucial factor. Traditionally, developing mobile applications required writing separate codebases for Android (using Java or Kotlin) and iOS (using Swift or Objective-C), which significantly increased the time, cost, and complexity of development and maintenance (Alsaid et al., 2021). This is overcome by using React Native, a widely used open-source framework that enables the development of cross-platform applications from a single codebase, thereby increasing development efficiency.

This study investigates how different types of databases affect performance within the React Native environment, with a particular focus on working with large datasets such as a German collocation dictionary. The experimental part of the work utilizes four different data management technologies: AsyncStorage, SQLite, TinyBase, and Realm. As part of the comparison, the performance of these solutions was analyzed depending on the size of the dataset, specifically the number of rows, with particular focus on measuring the time required to load and display data within the application.

The aim of the study is to determine which technology offers the best performance in the context of React Native applications when working with local data and to provide guidelines for choosing a database depending on the specific requirements of the project.

REACT NATIVE

React Native is an open-source framework developed by Meta (formerly Facebook) that enables developers to build mobile applications for both iOS and Android platforms using a single codebase. It is based on JavaScript and leverages the popular React library for building user interfaces. This approach significantly reduces development time and cost, as there is no need to maintain separate codebases for different platforms. One of the key features of React Native is its ability to render components using native APIs, providing a look and feel that is consistent with

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platform-specific user experiences, as illustrated in Figure 1. Unlike hybrid frameworks that rely on WebView, React Native applications run natively, which typically results in better performance and smoother animations. React Native also supports a wide range of third-party libraries and native modules, allowing developers to integrate device specific features like camera access, GPS, and push notifications with ease. Its hot reloading functionality speeds up the development process by allowing developers to see changes in real time without rebuilding the entire app. Overall, React Native is a powerful and flexible solution for cross-platform mobile development, making it a popular choice among startups and large companies alike that aim to reach a broader audience with a unified development effort (Eisenman, 2015).

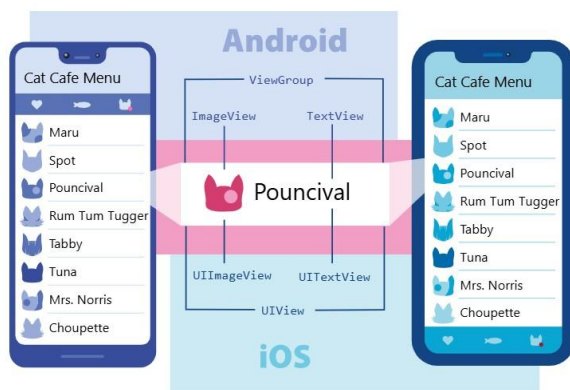


Figure 1. Examples of views used in Android and iOS applications (React Native – Native Components, 2025).

Expo is used for developing React Native applications. Expo has been actively involved in the development of React Native from the very beginning. Expo released the first community libraries just a few months after the release of React Native in 2015. In the same year, Expo developed the React Native Directory – a directory where React Native libraries can be searched and explored.

In 2016, Expo participated in organizing the first React Conf event and was the first independent developer community to support the release of a React Native version. Expo helped add async functions to React Native as well as update the new architecture in the open-source project (Saarikoski, 2025).

In 2024, Expo became the first official React Native framework for application development (React Conf, 2024).

Expo is a toolchain built around React Native to help developers start their projects quickly. Expo provides a set of tools and services to develop, build, deploy, test or even run simulators on the specific platform from the same codebase. Specifically, it offers a collection of ready solutions such as device accelerometer, camera, notifications, geolocation, etc. (Van, 2020).

STORAGE SYSTEMS AND DATABASES

AsyncStorage is a local data storage system used in React Native applications. It allows developers to store data on the user's device in the form of key-value pairs. The storage mechanism is asynchronous, meaning that data operations such as saving or retrieving run in the background without interrupting the main execution thread of the application. This contributes to better app performance and a smoother user experience (Huynh, 2023).

Stored data in AsyncStorage remains persistent across app restarts, making it suitable for maintaining state, user preferences, session tokens, or other small pieces of data that need to be retained between uses. However, it's important to note that AsyncStorage does not encrypt data, which makes it easily accessible but also raises security concerns for sensitive information.

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Due to its simplicity and ease of use, AsyncStorage is often chosen for basic offline data persistence in React Native apps, particularly when working with smaller datasets that do not require complex querying or relational structures.

SQLite is a lightweight, relational database engine commonly used in mobile applications for local data storage. In React Native, SQLite allows apps to store structured data directly on the device in a persistent and efficient way. It uses SQL queries to create, read, update, and delete data within local database files (Gaffney, 2022).

This approach is especially useful for applications that require managing moderate amounts of data offline, such as note-taking apps, inventories, or personal information managers. SQLite supports complex queries and relationships between data, providing more flexibility than simple key-value storage systems (Kreibich, 2010).

Because the database is stored locally, React Native apps using SQLite can operate without an internet connection, ensuring data availability at all times. Although it may have some limitations regarding concurrent writes and schema migrations, SQLite remains a reliable solution for many mobile apps needing fast and persistent local storage (Bhosale, 2015).

TinyBase is a small and fast database library for managing state and data in JavaScript apps, including React Native. It provides a flexible in-memory data store focused on ease of use and performance, rather than persistent storage (Danielsson, 2016).

In React Native, TinyBase helps efficiently handle complex state and relational data during app runtime. It supports tables, records, and relationships, similar to relational databases but without slow disk operations.

Its lightweight design and simple API make it easy to integrate with React Native's component lifecycle, enabling automatic updates and smooth rendering when data changes.

While TinyBase doesn't offer built-in persistent storage, it can be used alongside tools like AsyncStorage or SQLite to save and load data as needed. Overall, TinyBase is a useful tool for managing app state and complex data with high performance (TinyBase, 2025).

Realm is a mobile database built for modern apps, offering an easy-to-use, high-performance, and offline-first solution. Unlike traditional databases, it uses an object-oriented model, letting developers work with native objects instead of SQL queries (Danielsson, 2016).

In React Native, Realm efficiently manages complex data locally and supports reactive updates, ensuring UI components sync automatically when data changes. It stores data in a zero-copy format, improving read/write speeds, and offers features like encryption, synchronization with backend servers, and fine-grained permissions.

Realm handles complex relationships and queries without losing performance, integrates well with React Native's lifecycle, and supports transactions for data integrity. Although it requires setup and can increase app size, its benefits make it ideal for data-heavy mobile apps (Andersson, 2018).

In summary, Realm provides a powerful, scalable, and secure local database with real-time updates and synchronization, perfect for modern mobile development (Cobley, 2022).

IMPLEMENTATION

The motivation for testing various mobile database solutions stemmed from the development of a German collocation dictionary within the scope of the DeSKoll project (DeSKoll, 2025). To streamline development across platforms and avoid maintaining separate codebases for iOS and Android, the React Native framework was selected.

For experimental purposes, a simplified English word dictionary was utilized (OPTED-Dictionary, 2025), consisting of four columns: Word, Count, POS (part of speech), and Definition. In order to reduce complexity during testing, only the Word and Definition columns were considered, while the specific semantic content of the data was not of significance.

Datasets containing 100, 200, 500, 1000, 2000, 5000, 10000, 20000, 50000, and 100000 rows were loaded using four distinct methods. The upper limit of 100,000 rows was chosen based on the projected maximum size of the final collocation dictionary. The dictionary will have significantly fewer rows but more columns, so these measurements will be relevant.

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Identical user interface layouts were developed for each of the four data loading approaches, ensuring consistency across test scenarios.

All tests were performed in the Expo Go environment, utilizing an iPhone simulator and an Android emulator to ensure cross-platform compatibility. The layouts used for testing are presented in Figure 2.

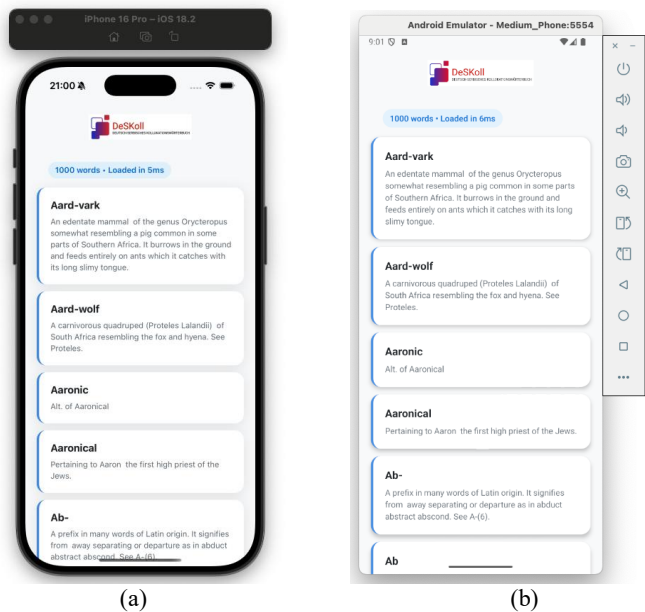


Figure 2. Application layout in React Native for testing on simulator for (a) iOS, (b) Android.

The first loading method uses AsyncStorage for local storage and display of the dictionary. When the application starts, the *useEffect* hook is triggered, performance measurement begins, and the app attempts to load the dictionary from memory. If data exists, it is parsed and set to state, then displayed using a *FlatList*. The data flow diagram from the AsyncStorage local database to the screen is shown in Figure 3.



Figure 3. Data flow: AsyncStorage → Screen (React Native).

In the second approach, an SQLite database is used for storing and displaying the dictionary. Data from the SQLite database is loaded using the expo-sqlite API through the useSQLiteContext hook. When the screen is focused, the *loadData* function is triggered, executing the SQL query *SELECT * FROM Dictionary* to retrieve all entries from the dictionary table. The query results are stored in the component's state (data), which automatically triggers the rendering of the list. The time taken to load the data is measured using *Date.now()* and displayed to the user. The dictionary is displayed using the *FlatList* component, which efficiently renders each word and its definition as a list on the screen. The data flow diagram from the SQLite local database to the screen is shown in Figure 4.

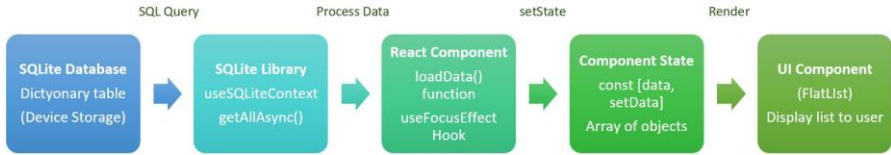


Figure 4. Data flow: SQLite → Screen (React Native).

The third approach combines an SQLite database with the TinyBase library for efficient data management and display. At the start, the Dictionary.db database is copied into the app's working directory. After that, the SQLiteProvider enables access to the database using expo-sqlite. The DataLoader component executes the SQL query *SELECT Word, Definition FROM Dictionary* to retrieve all words and their definitions. The resulting data is then written into the TinyBase store, where each word is used as a row ID and the definition as a cell. Once the data is loaded, the TinyBase context (TinyBaseProvider) wraps the entire app to allow access to the data via TinyBase hooks. The Dictionary component uses *useRowIds* to get all word keys, while DictionaryItem uses *useCell* to display the definition for each word. The data is rendered using FlatList, allowing for performant and dynamic display of dictionary items within the user interface. The data flow diagram from the SQLite local database throw TinyBase library to the screen is shown in Figure 5.

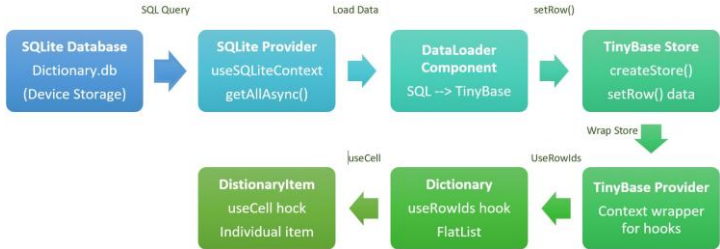


Figure 5. Data flow: SQLite → TinyBase → Screen (React Native).

The fourth method uses Realm, a high-performance local database, for storing and displaying the dictionary within the React Native application. The loading process starts by checking whether the Realm file (Dictionary.realm) exists in the local *documentDirectory* folder. If it does not exist, the database is automatically copied from the assets directory using the expo-file-system and expo-asset libraries. This process is automated in the *copyRealmFileIfNeeded* method, enabling the use of a pre-populated database. After copying, the application uses the RealmService class to open the database and initialize the schema (DictionarySchema). The data is then retrieved directly from the database and displayed using the FlatList component. The data flow diagram from the Realm local database to the screen is shown in Figure 6.



Figure 6. Data flow: Realm → Screen (React Native).

RESULTS AND DISCUSSION

To determine the most suitable solution for local data storage in mobile applications built with the React Native framework, a comprehensive performance evaluation was carried out involving four widely used database systems: SQLite, AsyncStorage, TinyBase, and Realm. The goal was to assess efficiency in handling different data set sizes, with a focus on load speed.

The performance tests were conducted on both an iOS simulator and an Android emulator, providing cross-platform insights into how each database behaves under similar conditions. The

evaluation involved loading predefined datasets of increasing sizes, specifically: 100, 200, 500, 1000, 2000, 5000, 10000, 20000, 50000, and 100000 records. These datasets were designed to simulate real-world application usage, ranging from simple to complex data structures.

For each test scenario, the time required to load the dataset into memory was measured and recorded in milliseconds (ms). To ensure reliability and minimize the impact of potential background activity or fluctuations in the simulator/emulator environments, each test was repeated multiple times, and average values were calculated.

The numerical results of testing on the iOS simulator are shown in Table 1, and the graphic representation is presented in Figure 6.

Table 1. Measurement of the data load time in iOS simulator

Inputs	SQLite (ms)	AsyncStorage (ms)	TinyBase (ms)	Realm (ms)
100	36	3	23	1
200	41	3	37	2
500	47	5	50	3
1000	55	6	102	4
2000	59	6	191	9
5000	61	11	302	20
10000	68	18	352	46
20000	88	86	380	84
50000	141	238	1781	226
100000	224	437	3364	466

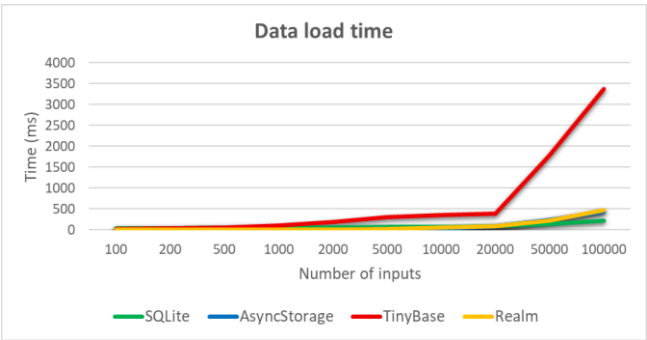


Figure 6. Measurement of the data load time in iOS simulator.

Similar results were obtained during testing on both the Android emulator and the iOS simulator, indicating consistent performance across platforms. The numerical results of testing on the Android emulator are shown in Table 2, and the graphical representation is presented in Figure 7.

Table2. Measurement of the data load time in Android emulator.

Inputs	SQLite (ms)	AsyncStorage (ms)	TinyBase (ms)	Realm (ms)
100	40	5	28	1
200	45	6	41	2
500	51	7	55	3
1000	62	8	113	5
2000	68	8	283	10
5000	82	11	319	21
10000	103	17	384	50
20000	148	143	434	86
50000	273	382	1783	224
100000	490	621	3526	578

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SQLite provides stable performance on both platforms. The loading times of small amounts of data are slow compared to other databases, but the growth is relatively uniform with the increase in the amount of data. this indicates stable and predictable performance.

AsyncStorage is very efficient for small to medium datasets, but not suitable for larger amounts of data. The responses are extremely fast for small amounts of data, however, after 20,000 entries there is a sudden spike, which indicates exponential growth and loss of efficiency with larger datasets.

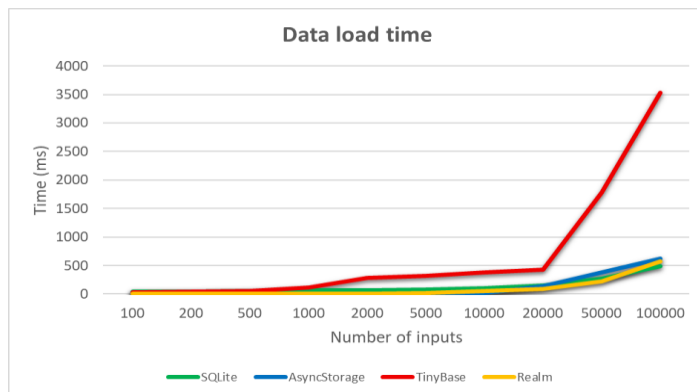


Figure 7. Measurement of the data load time in Android emulator.

TinyBase is not optimized for working with large datasets and shows extremely poor performance on both platforms. The performance is significantly weaker even with small datasets, and at 1,000 entries the growth is large, while at 20,000 entries it is exponential, which makes it unusable for large amounts of data.

Realm has the best performance for small amounts of data, however, performance degrades as the dataset grows. The growth is relatively linear up to 10,000 entries, after which there is a noticeable slowdown.

From the obtained results it can be concluded that Realm and AsyncStorage are the fastest for small datasets. The most stable performance was shown when using SQLite, with a uniform and predictable increase in loading time. The worst performance was obtained with TinyBase, with sudden exponential growth and very long times for large datasets.

CONCLUSIONS

The comparison of different types of data storage in React Native applications shows that the optimal choice of storage is highly context-dependent. There is no single solution that works best in every situation.

The choice depends on the specific requirements of the application, the expected data volumes, and the targeted platforms. For applications with predictable data sizes up to 10,000 entries, AsyncStorage represents an optimal choice due to its simplicity and good performance. For applications that require scalability and handling large amounts of data, SQLite is the only solution that provides consistent performance across all scenarios. Realm can be used in specific cases where its advantages for smaller data volumes can be leveraged, but it requires careful testing and monitoring. TinyBase is not recommended for production applications due to consistently poor performance on both platforms.

In summary, developers should carefully evaluate their application's requirements—such as data size and complexity, need for local storage, performance, and implementation simplicity – to choose the most appropriate solution.

Further studies should concentrate on evaluating performance using real-world datasets and diverse operation types, along with examining how factors like memory usage, battery

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consumption, and network traffic influence the overall efficiency of storage solutions in React Native applications.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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IMPLEMENTATION OF WAVELET SCALOGRAMS FOR AUDIO SIGNAL ANALYSIS

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ABSTRACT

In the past few decades, wavelets have found an important place in many fields due to their nature and advantages compared to other algorithms. When the focus is on signal processing, wavelets can be used as an algorithm for de-noising, frequency analysis, feature analysis, etc. The spectrogram is one of the most common visual representations of the signal in the frequency domain when the Fourier transformation is used. Wavelets have their algorithm for signal representation in the frequency domain, and it's called scalogram due to the nature of the scaling properties of the wavelet function.

This paper explores the application of the Continuous Wavelet Transform (CWT) for generating and analyzing scalograms. Audio signals from different direct current (DC) motor sounds are used as test data to demonstrate the effectiveness of this approach. All implementations and analyses are carried out using MATLAB software. The results highlight the advantages of wavelet-based analysis in capturing time-frequency characteristics that may not be easily observed with traditional Fourier-based methods.

Keywords: wavelets, frequency analysis, scalograms, continuous wavelet transform, direct current motor sounds.

INTRODUCTION

The development of technology in the modern era has enabled significant advancements in signal analysis and processing, particularly in the field of audio processing. One of the most intriguing approaches in this domain is converting audio signals into visual representations, which offer new possibilities for visualization and further analysis. This method of interpreting signals allows researchers to identify the frequency and time-domain characteristics of sound in an intuitive and informative way. The conversion of audio signals into images and further processing using wavelets has become a significant area of research and application. This interdisciplinary field enables the visualization and analysis of audio signals in a way that provides unique insights into their frequency characteristics.

One of the most powerful tools used for this purpose is wavelet transformation. Unlike traditional methods such as the Fourier transform, wavelet transformation enables simultaneous analysis of signals in both the time and frequency domains, providing more precise information about the signal's structure. The application of this method results in spectrograms and scalograms, which visually represent the dynamics of the signal across different frequency ranges.

The objectives of this paper are: first, to provide the reader with a thorough understanding of the process of converting audio signals into images (scalograms), and second, to demonstrate how these images can be further analyzed and processed to extract key information. Through practical examples in MATLAB, specific implementations and results will be presented.

This study aims to contribute to the understanding of the complexity of audio signals through visualization and analysis, providing readers with tools for further research and application in various fields, from audio engineering to medical diagnostics. The goal of this paper is to emphasize the importance of visualizing audio signals for a deeper understanding of their characteristics.

For the purpose of this paper, various audio sounds from direct current motors are used. All sounds are recorded in the laboratory and the production hall. Some of the important characteristics of these motors are: input voltage from 12V to 13V, no load speed (rotation per minute) about 80, maximum output power from 18W to 25W, approximate dimensions 16 x 13.5 x 4.5cm. Due to the paper's length, only representative examples are used for this paper.

The paper is organized into four sections including introduction and conclusion. The second section provides relevant background theoretical information. The third section presents a time and frequency analysis of DC motor sounds. The fourth section gives the results of the analysis of wavelet-based scalograms.

WAVELETS

Wavelets are fundamental mathematical tools that can be used for signal and image analysis and processing (Graps, 1995). In the context of signal analysis, wavelets enable the understanding and representation of complex signals through localized functions that expand in time or frequency. This approach allows for efficient detection and analysis of various signal characteristics, such as changes in frequency, amplitude, or shape (Damnjanović et al., 2020).

In image processing, wavelets are used to separate different scales and details of an image, which is useful in applications such as image compression, noise reduction, and edge detection (Kingsbury, 1999). The advantage of wavelets over traditional methods like the Fourier transform lies in their ability to provide better time-frequency localization, which is crucial for analyzing rapidly changing signals or images with varying levels of detail (Sifuzzaman et al., 2009). By using wavelets, it is possible to efficiently perform multichannel analysis, allowing for improved pattern recognition and feature extraction in both signals and images.

In its simplest form, a wavelet represents a wave function of limited duration whose average value is zero (Damnjanović et al., 2019). Wavelets have been developed to enhance existing signal-processing algorithms and address certain limitations. Basic wavelet $\psi(x)$, the so-called “mother wavelet” is defined as:

$$\psi_{a,b}(x) = \frac{1}{\sqrt{a}} \psi\left(\frac{x-b}{a}\right), a > 0, \quad (1)$$

where a is the scaling parameter and b is the translation parameter. Selection of the parameters is the most difficult task in the wavelet function, and it depends on the shape and complexity of the wavelet function (Damnjanović et al., 2021).

All wave transformations can be considered forms of time-frequency representation for continuous (analog) signals, making them similar to harmonic analysis. The Continuous Wavelet Transform (CWT) uses wavelets that enable signal analysis in continuous time, decomposing the signal into localized functions in time and frequency (Guido et al., 2020). This approach is similar to Fourier analysis but allows for better time-frequency localization. CWT is defined by the inner product of the function (f) and the basis “mother” wavelet $\psi_{a,b}(x)$:

$$CWT_f(a,b) = (f, \psi_{a,b}) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(x) \psi^*\left(\frac{x-b}{a}\right) dx, \quad (2)$$

Today, there are numerous wavelets used in various fields of signal analysis, image processing, and mathematics. Some of the fundamental types of wavelets include: Haar, Daubechies, Coiflets, Symlet, Biorthogonal, Reverse biorthogonal, Meyer, Morlet, etc (Damnjanović et al., 2018).

Scalograms

The scalogram is a graphical representation of the time-frequency content of a signal, obtained using the wavelet transform, which enables signal analysis at different time scales and frequencies (Rioul and Vetterli, 1991). Unlike the spectrogram, which relies on the Short-Time Fourier Transform (STFT) and fixed window sizes for analysis, the scalogram uses wavelet functions with variable-sized windows. This approach provides high temporal resolution for rapid changes in the signal (high frequencies) and high-frequency resolution for slower oscillations (low frequencies), making it particularly useful for analyzing non-stationary signals (Bolos and Benitez, 2014).

In a scalogram:

- The horizontal axis represents time, allowing insight into when specific signal features appear.
- The vertical axis shows scale, which can often be converted to frequency for easier interpretation.
- The color intensity or shading indicates the signal energy at a given scale at a particular time, visualizing how the signal's energy evolves over time.

The wavelet transform, which underlies the scalogram, uses wavelet functions of various shapes (such as Morlet, Haar, or Daubechies wavelets), allowing adaptive analysis based on signal characteristics. Unlike STFT, which is constrained by the trade-off between time and frequency resolution, the wavelet approach provides a more detailed and flexible insight into the local characteristics of a signal.

Scalograms are widely used in biomedical signal analysis (e.g., EEG and ECG) (Bialasiewicz, 2015), (Kumar et al., 2004), seismic signal processing (Li et al., 2006), audio signal analysis (Peng et al., 2002), and pattern recognition (Sharan, 2020), (Salles and Ribeiro, 2023). Due to their ability to identify transients, sudden changes, and complex patterns in signals, scalograms have become an indispensable tool in modern signal processing and scientific research. A schematic representation of the frequency-time plane, which is important in the process of creating a scalogram, is shown in Fig. 1.

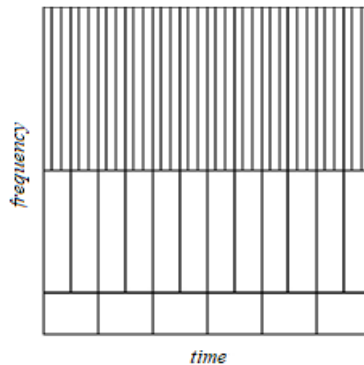


Figure 1. Frequency-time plane using wavelets.

RESULTS AND DISCUSSION

As it was mentioned before, for the purpose of this paper, MATLAB software is used. At the beginning, it is important to show examples of DC motor sounds in the time and frequency domains. Two representative examples are selected for further analysis. The differences between the two selected motors are that one operates without any faults, while the other has a fault in its operation. The time domain is shown in Fig. 2.

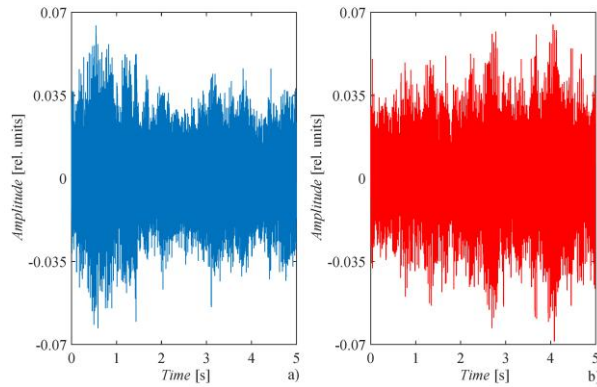


Figure 2. Time domain of two DC motor sounds: a) without fault, b) with fault in work.

Representative frequency domains of selected motors are presented in Fig. 3.

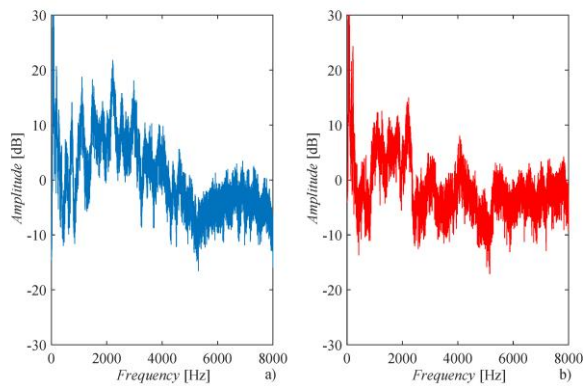


Figure 3. Frequency domain of two DC motor sounds: a) without fault b) with fault in work.

Analyzing representative audio signals in the time and frequency domains can be challenging without applying specific methods, as it was shown in Fig. 2 and 3. In the time domain, the signal is represented as a function of time, but this approach doesn't provide enough information about the signal's frequency components. Noise and interference can also obscure the signal's true characteristics. On the other hand, analyzing the signal in the frequency domain reveals its frequency distribution, but this method can still be difficult to interpret without advanced techniques. Even using the Fourier transform may result in the loss of important details in the time component.

To effectively analyze audio signals, advanced methods like wavelet transform, spectrogram, or scalogram analysis are needed, as they combine both domains and allow for a better understanding of the signal's features. In the next lines, scalograms of selected signals will be presented. Figure 4 presents a scalogram of the DC motor sound without fault, while Figure 5 presents a scalogram of the DC motor sound with fault. The analysis employs the Morlet wavelet to generate the scalogram. The Morlet wavelet uses a complex representation for improved localization and analysis of frequency components. It is characterized by the use of only positive frequency components and is particularly suitable for precise analysis of complex signals (Silik et al., 2021).

On the x-axis, the time interval of the signal is shown in seconds, while the y-axis represents the logarithmic frequency in Hz (from low to high frequency). On the right side, the scale of the intensity of energy (magnitude) at different moments in time is given. Brighter colors indicate a

higher presence of a certain energy at a given moment. Brighter colors (yellow) represent higher energy at that frequency, while darker colors (blue) represent lower energy.

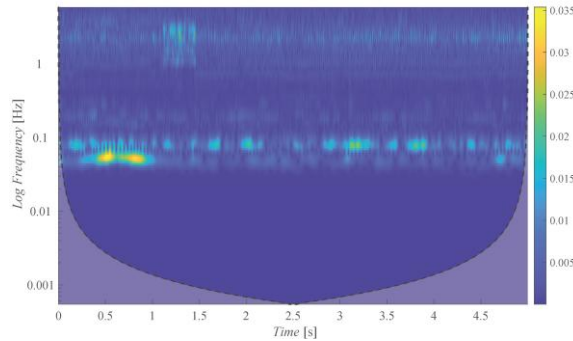


Figure 4. Scalogram of the DC motor sound without fault.

A comparison of the two scalograms shows that both signals exhibit dominant energy at approximately the same frequencies. However, over time, it is evident that the faulty motor signal exhibits more fluctuations. This results in the motor having certain deficiencies in its operation. Such conclusions could not be observed from the spectra shown in Fig. 3.

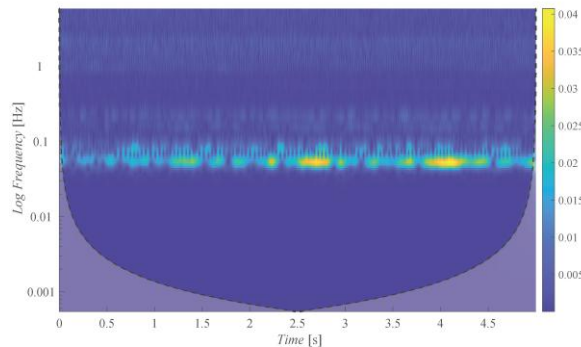


Figure 5. Scalogram of the DC motor sound with a fault.

The identification of dominant frequencies in a signal represents a key step in the analysis of time-frequency characteristics. Dominant frequencies are those components that have the highest energy contribution and the most pronounced intensity within certain time intervals. It is often useful to extract only those frequencies that exceed a certain energy threshold, ignoring weaker components that may result from noise or less significant signal features. This approach not only enables a better analysis of the dominant frequency components but also contributes to a clearer understanding of the signal's structure over time. The following figures show the scalograms of the previously analyzed signals, with a focus placed specifically on the dominant frequencies (Figure 6 for motors without faults, and Figure 7 for motors with faults).

Now that the dominant frequencies are more pronounced, the previous statement is confirmed: the energy of both signals is concentrated at approximately similar frequencies, but the faulty motor signal exhibits more distinct details in the scalogram. It is important to note that the y-axis differs in this type of scalogram, as a logarithmic scale is no longer used, making the frequencies clearly visible.

This method of analysis is excellent for further feature extraction from signals and the creation of a corresponding database. Such a database would be suitable for further processing, for example, as images, with the aim of classifying a large number of samples, distinguishing between motors without fault and those with fault.

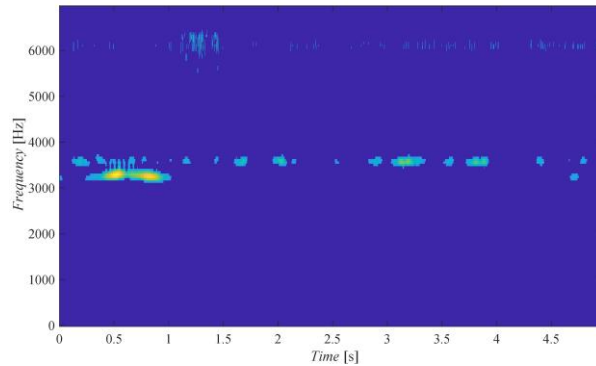


Figure 6. Scalogram with dominant frequencies of the DC motor sound without fault.

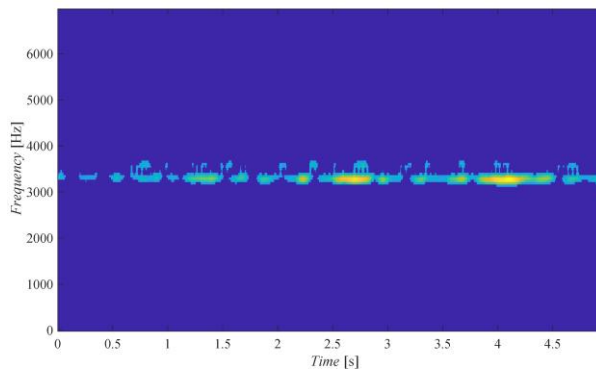


Figure 7. Scalogram with dominant frequencies of the DC motor sound with fault.

CONCLUSIONS

Converting an audio signal into a type of image can be a highly developed and interesting discipline within scientific research. If such images are treated as features of the audio signal, classification could later be performed. Wavelets represent one of the methods for processing audio signals and transforming them into scalograms, where certain frequency features can be observed.

This paper offers such a possibility and describes in detail the process of image formation, that is, the formation of a scalogram using wavelet transform. The entire procedure is demonstrated on sound recordings of DC motors, where one motor had a fault in its operation while the other operated correctly (without fault).

The Morlet wavelet was used, and in addition to the basic scalogram analysis, a detailed analysis was performed by further processing the obtained scalograms in order to highlight the dominant frequencies. In this procedure, the focus was on identifying frequencies that exceed a certain energy threshold. As a result, the scalograms became clearer, with dominant frequencies being more pronounced, thus facilitating further analysis.

Future work would be based on the classification of the obtained images, that is, scalograms of a large number of audio signals. It is always advisable to use a different type of wavelet as well, in order to compare the obtained results and select those with the greatest potential.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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AN ANALYSIS OF KNOWLEDGE SOURCES IN THE FIELD OF THE INTERNET OF THINGS

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ABSTRACT

This research presents an analysis of the application and acceptance of various standards in the field of the Internet of Things (IoT). Employing t-test statistical analysis, the study analyzes differences between groups of standards in three key categories: implementation complexity, adoption level, and citation frequency. The results show that communication and networking standards—such as IEEE 802.15.4, CoAP, and 6LoWPAN—are cited significantly more often and demonstrate higher adoption rates in both scientific literature and industry, compared to architectural and security standards, including IEEE P2413, ISO/IEC 30141, and ISO/IEC 27030. However, no statistically significant differences were found in implementation complexity among the analyzed groups. Based on these findings, the study recommends the continued development and deployment of communication standards, while suggesting that architectural and security standards be enhanced through simplified implementation and stronger integration into industrial solutions. Future research could further examine the influence of various factors on the acceptance and implementation of standards across different industrial sectors.

Keywords: Internet of Things, standards, communication, security, t-test, citation frequency, adoption

INTRODUCTION

Standards in the field of communications, networking, architecture, and security represent the basis for the development of technological systems, enabling interoperability among various devices, platforms and applications (Miloslavskaya et al. 2019). In recent decades, especially with the development of the Internet of Things (IoT) and 5G networks, these standards have become crucial for the efficient functioning of modern technologies. Standards such as IEEE 802.15.4, CoAP, 6LoWPAN, as well as architectural and security standards like IEEE P2413, ISO/IEC 30141, and ISO/IEC 27030), provide essential guidelines for the implementation and utilization of emerging technologies (Wagle and Pecero, 2019). The goal of this research is to analyze three key parameters related to standards: complexity of implementation, degree of acceptance and frequency of citations, in order to establish statistically significant differences between communications/networking standards and those in the domains of architecture and security.

The introduction of new technologies into practice often faces challenges related to implementation, acceptance within industry and the scientific community, as well as the frequency of citations in the literature. The t-test method is applied to quantify statistical differences between two sets of standards and to gain relevant insights into factors that may influence their implementation (Kyun, 2015). Given that communications and networking standards have broad application in IoT devices and industrial networks (Porkodi and Bhuvaneswari, 2014), while architectural and security standards are more narrowly focused on data protection and the development of secure infrastructures, the analysis of these parameters can help better inform future research and guide the development of new technologies.

MATERIALS AND METHODS

The t-test is a statistical method used to compare the means of two groups and to determine whether the observed differences are statistically significant or occurred by chance. In this study, an independent samples t-test was used, as the two groups being compared are mutually independent and the goal was to assess to determine whether there is a statistically significant difference between their mean values (Kyun, 2015). Also, a simple t-test was applied to analyze the differences in three key parameters: implementation complexity, level of adoption and citation frequency between the two groups of standards.

The three categories of analysis explored in this paper are as follows:

- Implementation complexity – This parameter measures the level of difficulty involved in implementing the standards in practice. Complexity may depend on technical requirements, the need for specific hardware or software resources, and compatibility with existing systems.
- Degree of acceptance – This parameter refers to how well the standards are accepted and utilized in industry and academia. The degree of acceptance can indicate how well the standards are implemented in real projects and how they are adopted by users and development teams.
- Citation frequency – This parameter measures how often the standards are referenced academic and industry publications. Citation frequency serves as an indicator of the standards' relevance within the scientific community and their role in research, technological development, and innovation.

Selection of standards and data collection

Two groups of standards were selected for analysis:

- Group 1: Communications and networking standards - IEEE 802.15.4, CoAP, 6LoWPAN
- Group 2: Architectural and security standards - IEEE P2413, ISO/IEC 30141, ISO/IEC 27030

Data on implementation complexity (Table 1), degree of acceptance and frequency of citations for these standards were collected through a systematic search of academic literature using the Google Scholar search engine. The search enabled the collection of relevant data, which were then organized into a table containing values for each of the analyzed parameters. Based on these data, a t-test analysis was performed to assess whether statistically significant differences exist between the two groups of standards across all three categories.

Table 1. Presentation of collected data for analysis.

Standard	Complexity of implementation	Degree of acceptance	Frequency of citations
IEEE 802.15.4	7	10	28.800
CoAP	6	9	24.600
6LoWPAN	8	8	21.400
IEEE P2413	9	4	580
ISO/IEC 30141	8	3	397
ISO/IEC 27030	9	2	44

The programming code for the t-test analysis (Figure 1) was written in the Python programming language (Wang et al., 2022). The standards were divided into two groups: communications and networking standards, and architectural and security standards. After that, a t-test analysis was performed for all three parameters, and the obtained results are printed in json format to improve readability and facilitate further interpretation.

```
import json
import scipy.stats as stats
import pandas as pd

# Definisanje podataka
data = {
    'Standard': ['IEEE 802.15.4', 'CoAP', '6LoWPAN', 'IEEE P2413', 'ISO/IEC 30141', 'ISO/IEC 27030'],
    'Slozenost implementacije': [7, 6, 8, 9, 8, 9],
    'Stepen prihvacenosti': [10, 9, 8, 4, 3, 2],
    'Ucestalost citiranja': [28800, 24600, 21400, 580, 397, 44]
}

# Kreiranje DataFrame-a
df = pd.DataFrame(data)

# Deljenje podataka na dve grupe: komunikacija/mreža i arhitektura/bezbednost
group1 = df.iloc[:3] # IEEE 802.15.4, COAP, 6LOWPAN
group2 = df.iloc[3:] # IEEE P2413, ISO/IEC 30141, ISO/IEC 27030

# Izračunavanje t-testa za sve kolone
results = {}
for column in ['Slozenost implementacije', 'Stepen prihvacenosti', 'Ucestalost citiranja']:
    t_stat, p_val = stats.ttest_ind(group1[column], group2[column])
    results[column] = {'t_stat': t_stat, 'p_val': p_val}

# Pretvaranje rezultata u JSON format
results_json = json.dumps(results, indent=4)
print(results_json)
```

Figure 1. Programming code for t-test analysis.

RESULTS AND DISCUSSION

The results of the t-test analysis provide key insights into various aspects of the standards used in communications, networking, architecture, and security (Doug, 2019). Regarding implementation complexity, although the standards in the fields of architecture and security yielded slightly higher t-statistic values, the difference was not statistically significant. This result suggests that the implementation complexity between the standards in different domains is not substantial enough to have a significant impact on decisions regarding their implementation in practice (Ross and Willson 2017). On the other hand, statistically significant differences were found in the categories of degree of acceptance and frequency of citation, with standards from the field of communications and networking being significantly more accepted and more often cited in the literature. This indicates that such standards have become crucial for the development of new technologies and are already well-integrated into numerous industrial and research projects.

These results have significant implications for both industry and academia. In the industrial sector, communications and networking standards show strong potential for broader application and further development of new technologies. For example, protocols such as IEEE 802.15.4 and CoAP play a key role in the Internet of Things (IoT), particularly in enabling connectivity among heterogeneous devices. Furthermore, the high frequency of citations of these standards indicates that their principles and guidelines are widely used in academic research, which supports their applications in creating new solutions for device connectivity, data management, and network optimization. On the other hand, while architecture and security standards may be less frequently cited, they nonetheless play a critical role in defining security frameworks and infrastructure guidelines. These aspects are essential for the future development of IoT systems with enhanced security protection.

Although the results of the analysis are informative, there are certain limitations of this study. First, the analysis relied on data available in Google Scholar, which may have led to the exclusion of standards that are underrepresented in academic literature. Additionally, while the t-test is useful for detecting statistical differences between two groups, it does not provide deeper insights into the underlying causes of those differences (Sarstedt and Mooi 2019). In future, the use of other statistical methods, such as regression (Sarstedt and Mooi 2019) or analysis of variance (Emsley, 2000), could provide a more detailed understanding of the factors influencing acceptance, citation and complexity of standard implementation. Moreover, incorporating additional variables—such as regional differences in standard adoption and market evolution—could further enrich the findings.

To assess implementation complexity, the independent t-test yielded the following results for the two groups of standards:

- t-statistics: -2.50
- p-value: 0.067

This result shows that there is a difference in implementation complexity between the two groups of standards, but this difference is not statistically significant at the 0.05 significance level. A p-value of 0.067 indicates that the difference is not sufficient to conclude that there is a clear statistical difference. However, considering the p value, the difference is marginally significant, which means that additional research could bring clearer insights. Based on this result, we can assume that architecture and security standards may be more complex to implement compared to communication and network standards, but this difference is not convincing enough to be considered statistically significant.

A t-test was also applied to analyze the degree of acceptance of both groups of standards in industry and academia. The obtained results are as follows:

- t-statistics: 7.35
- p-value: 0.002

These results indicate a statistically significant difference between the two groups. A p-value of 0.002, which is well below the 0.05 threshold, confirms that the degree of acceptance differs significantly between communications and networks standards and those related to architecture and security. Standards such as IEEE 802.15.4, CoAP, and 6LoWPAN show a much higher level of acceptance in industry and academia compared to standards like IEEE P2413, ISO/IEC 30141, and ISO/IEC 27030. This suggests that communication and network standards play a central role in the widespread adoption of emerging technologies, whereas architecture and security standards remain less prominent within industrial applications and scholarly research.

When it comes to the analysis of the frequency of citations, a t-test yielded the following results:

- t-statistics: 11.45
- p-value: 0.0003

The very low p-value (0.0003) indicates a statistically significant difference in citation frequency between the two groups of standards. Communication and network standards—IEEE 802.15.4, CoAP, and 6LoWPAN—are cited significantly more often in scientific literature than architecture and security standards such as IEEE P2413, ISO/IEC 30141, and ISO/IEC 27030. This suggests that communication-related standards are not only more widely referenced in academic research, but also likely play a more prominent role in ongoing technological development. In contrast, the lower citation frequency of architecture and security standards may reflect their more limited presence in published studies or less frequent application in research contexts.

For better visualization, the graphs below present the t-statistics and p-values for each of the three analyzed categories. These graphs provide a clear overview of the statistical differences between the two groups of standards.

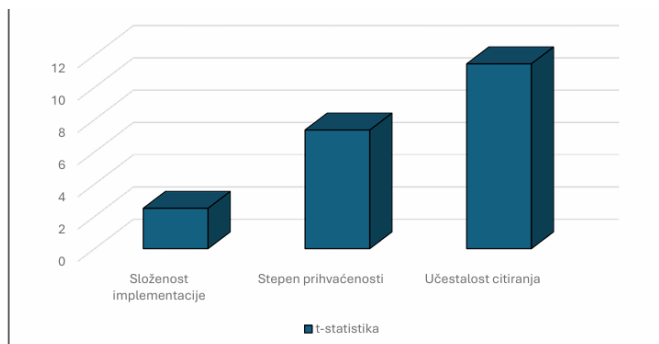


Figure 2. Graphic display of t-statistics by analysis category.

Figure 2 presents the t-statistics for the three categories: complexity of implementation, degree of acceptance, and frequency of citations. The t-statistics for complexity of implementation

suggests a marginal difference, while the t-statistics for degree of acceptance and frequency of citations are substantially higher, indicating statistically significant differences in these categories.

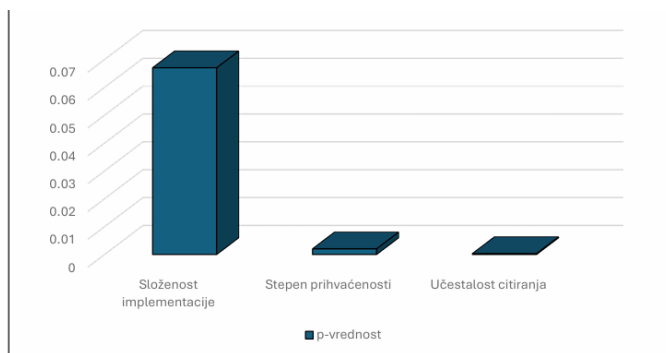


Figure 3. Graphic representation of p-values by analysis category.

Figure 3 presents the p-values corresponding to the three analysis categories. The p-value for implementation complexity is close to 0.05, suggesting a marginal significance. In contrast, the p-values for degree of acceptance and frequency of citations are considerably lower, clearly indicating statistically significant differences between the two groups of standards in these categories.

CONCLUSIONS

The t-test analysis revealed statistically significant differences between the two groups of standards in two out of the three examined categories: degree of acceptance and frequency of citations. Specifically, standards in the field of communications and networks—such as IEEE 802.15.4, CoAP, and 6LoWPAN—demonstrated significantly higher levels of acceptance in both industry and academia, as well as greater citation frequency in the scientific literature. However, the difference in the complexity of implementation was not statistically significant, suggesting that implementation challenges are relatively similar regardless of the standards' domain.

Based on the results of this analysis, it is recommended that both the industry and the academic community continue to prioritize the application and development of standards in the field of communications and networks, given their strong acceptance and high citation frequency. To enhance the implementation of standards in the fields of architecture and security, efforts should be directed toward simplifying their application and promoting their integration into industrial solutions.

Future research could focus on a more detailed analysis of the influence of various factors on the acceptance and implementation of standards. For example, examining how standard adoption varies across sectors such as telecommunications, automotive, or smart cities could offer a broader perspective on where specific standards have the most impact. Additionally, the use of other methods of data analysis, such as network analysis or root cause research, can provide a deeper understanding of the dynamics of citation and adoption of standards, thus providing a clearer insight into how both industry and academia are shaping the technologies of the future.

ACKNOWLEDGMENT

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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DESIGN OF RECOMMENDER SYSTEMS IN E-COMMERCE

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ABSTRACT

This research presents the design of a recommender system for an online store. The system utilizes user behavior data and purchase history to generate personalized product suggestions. Its main components include a recommender server and client modules. The recommender server performs the core recommendation logic independently of the online store, while the client modules integrate with the store's interface to display recommendations to users. For data analysis and recommendation generation, the system employs a combination of K-Means clustering and collaborative filtering. K-Means clustering groups users based on similarities in their purchase history, while collaborative filtering suggests products based on the purchases of other users within the same cluster. The paper also addresses implementation challenges encountered during system development, including the selection of appropriate libraries and performance optimization. The results indicate that the system provides effective product recommendations and shows strong potential for future enhancements, such as the incorporation of additional user data and exploration of more advanced recommendation algorithms. Future work may focus on algorithm optimization, dataset expansion, and experimentation with emerging technologies.

Keywords: recommender system, e-commerce, K-Means clustering, collaborative filtering, personalized recommendations

INTRODUCTION

In modern business, online stores face the challenge of personalizing the customer experience and increasing sales efficiency. Recommender systems represent one of the key solutions to this problem as they enable the display of products that are most relevant to each user based on their previous activities and interests. This paper focuses on the design and implementation of a recommender system for an online store, with the aim of improving the user experience and optimizing the purchasing process.

The aim of this paper is to investigate and implement techniques for generating personalized product recommendations using data about users and their purchase history. Based on these data, the system will provide recommendations that can increase the chances of additional sales as well as enhance customer satisfaction.

To implement the system, two key techniques were used: K-Means clustering and collaborative filtering. K-Means clustering is an algorithm that groups users into clusters based on the similarity of their purchases, while collaborative filtering enables the generation of recommendations based on the activities of other users within the same cluster. These techniques allow recommendations to be based on the behavior of similar users, thereby achieving a high level of personalization and relevance.

The paper provides a detailed explanation of the methodology used for data analysis, system design, and system implementation, with an emphasis on challenges encountered and solutions applied during development.

MATERIALS AND METHODS

K-Means clustering is one of the most popular unsupervised learning algorithms, used to group data into clusters based on their similarity (Lu et al., 2012). The main idea behind K-Means clustering is to divide the data into k clusters, where each cluster represents a group of data points

that are similar to each other, while being different from those in other clusters. The algorithm consists of several key steps:

- Initialization: Selection of the initial number of clusters (k) and random selection of initial cluster centers.
- Cluster assignment: Each data point is assigned to the closest cluster center.
- Update centers: The center of each cluster is recalculated as the mean of the data within that cluster.
- Iteration: The process of assigning data to clusters and updating centers is repeated until convergence is achieved, i.e. until the positions of the cluster centers stabilize.

In the context of recommender systems, K-Means clustering is used to group users based on their purchase history. Users within the same cluster share similar preferences and behaviors, which enables more accurate and effective product recommendations based on the activities of users from the same cluster (Basu et al., 1998).

Advantages of K-Means clustering:

- Simplicity and efficiency: K-Means is easy to implement and it is computationally efficient, especially when applied to large datasets.
- Scalability: The algorithm is scalable and capable of processing large amounts of data.
- Ease of interpretation: K-Means facilitates the interpretation of user groups, as each user is assigned to a single cluster, and the center of the cluster can offer insights into the characteristics of users within that group.

Disadvantages of K-Means Clustering:

- Predefined number of clusters: The number of clusters (k) must be specified in advance. Selecting an appropriate k can be challenging, as too few or too many clusters can result in poor recommendations.
- Sensitivity to initialization: K-Means is sensitive to the initial placement of cluster centers, which can lead to suboptimal results if the initialization is not well chosen.
- Lack of flexibility in cluster shape: K-Means assumes that the clusters are spherical and evenly sized, which can be problematic when dealing with non-linear or irregularly shaped data distributions.

Collaborative filtering is a technique used to recommend products based on the behavioral data of other users. This method relies on the assumption that users who have exhibited similar preferences or behaviors in the past tend to have similar interests in the future (Lu et al., 2012). Collaborative filtering can be divided into two main types (Schafer et al., 2001):

- User-based filtering: Recommendations are generated based on similarities between users. If User A has similar preferences to User B, the products purchased by User B can be recommended to User A.
- Product-based filtering (Item-based): Recommendations are generated based on similarities between products. If a user has already purchased product X, other products frequently purchased together with X may be recommended.

In both cases, the analysis of user behavior, such as previous purchases, product ratings or clicks on products, is crucial in order to create relevant recommendations (Chen et al., 2004).

Advantages of collaborative filtering:

- Simplicity: Collaborative filtering does not require a detailed understanding of the product or user, as it relies only on the history of interactions and behavior.
- Personalization: Recommendations are highly tailored to each user, as they are based on their previous activities and preferences.

Disadvantages of collaborative filtering:

- Cold start problem: For new users or new products, collaborative filtering may struggle to generate recommendations because due to insufficient data about users or products.
- Data sparsity: In large systems, user and product data can often be very sparse (e.g., a user may have purchased only a few products), which can lead to poor recommendations.
- Scalability: Collaborative filtering can become computationally intensive in a system with large numbers of users and products, especially when using user-based filtering.

By combining K-Means clustering and collaborative filtering, it is possible to create a recommender system that uses the advantages of both approaches and minimizes their disadvantages (Aljunid, & Huchaiah, 2022).

RECOMMENDER SYSTEM DESIGN

The design of the recommender system for e-commerce is based on a two-component architecture, consisting of a server and a client component (Lourenco and Varde, 2020). Each of these components plays a specific role in the process of generating and displaying recommendations to users.

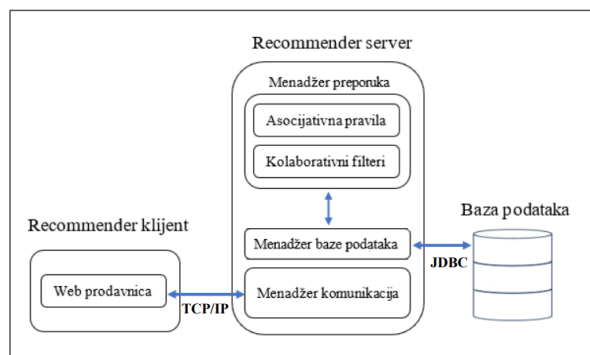


Figure 1. Recommender system design.

The server-side component represents the core logic of the system, responsible for processing data and generating recommendations. This component operates independently of the online store itself, which enables flexibility and easier integration with different platforms. The server uses data about users, their purchase history and preferences to generate personalized recommendations using K-Means clustering and collaborative filtering. The server's algorithms ensure that recommendations are based on relevant data and optimized for each user.

The client-side component is integrated into the online store and is responsible for interacting with the user. It communicates with the server to gather recommendations and display them to users. The client component is typically embedded within the store's user interface, such as personalized recommendation sections on the home page or within product pages. Communication between the server and the client is provided through an API, which enables sending referral requests and receiving responses in a format suitable for user-facing display.

The server component plays a key role in the recommendation generation process. Based on data about users and their previous purchases, the server uses algorithms to analyze and predict which products will be most interesting to individual users. By applying K-Means clustering, the server groups users with similar behavioral patterns, which enables personalized recommendations based on user activity within the same cluster. In addition, the server implements collaborative filtering to further enrich recommendations, using data on other users' interactions with products. This method allows the system to recommend products that other users, who are similar to the current user, have already bought or rated positively.

For each request sent by the client component, the server analyzes the available data and creates a list of recommended products. This process is done in real time, which allows the recommendations to be relevant and updated according to the current behavior of the user on the site.

Communication between the client and server components is provided through an API (Application Programming Interface), which enables efficient data exchange. The client component sends a request to the server to generate recommendations based on specific user data (such as purchase history, preferences, and browsing behavior), and the server responds with a list of products that match the user's requirements.

Communication is usually done in JSON (JavaScript Object Notation) format, a widely adopted standard for structured data transfer that allows for easy data handling on the client side. The client component then displays the recommended products on the user's interface in the form of interactive elements such as lists, carousels or product cards.

This interaction between the server and the client is crucial for providing a personalized and dynamic user experience. The server component provides the power of data analysis, while the client component ensures that users can easily access recommendations that match their interests and needs.

RECOMMENDER SYSTEM IMPLEMENTATION

For the implementation of the recommender system, a set of widely used tools and libraries is employed to enable efficient data processing, application of algorithms and user interface development. The key technologies used include:

- Pandas and NumPy: Used for data manipulation and analysis. These libraries facilitate simple and efficient data loading, filtering, and preprocessing, as well as working with large data sets in spreadsheet format.
- Scikit-learn: Used for implementing K-Means clustering and applying data-driven learning methods. Scikit-learn provides simple tools for training and evaluating models, as well as implementing algorithms such as clustering, regression, and filtering.
- Surprise: A library specialized in creating recommender systems. It is used to implement various collaborative filtering algorithms, such as user-based and item-based filtering. This library enables easy testing of different methods and their evaluation.
- Flask: This web framework is used to develop the server that manages the recommendation generation logic. It supports easy development of a RESTful API that communicates with client components in an online store and enables the generation of recommendations in real time.
- HTML, CSS, JavaScript: On the client side, basic web technologies are used to create the interface, with the aim of providing users with a simple and intuitive way to view recommended products.

Working with data is a key component in the implementation of a recommender system. At the initial stage, data about users and their purchase histories are loaded into a DataFrame using the Pandas library. The data undergoes a cleaning and normalization process [6]. The `dropna()` method is used to remove missing values, and the `scaling()` method is used to normalize numerical values.

For K-Means clustering, user purchase histories are encoded into numerical vectors, which are then used as input to the clustering algorithm. The data is structured in such a way that user similarities can be effectively analyzed and then assigned to appropriate clusters (Schafer, 2005).

For collaborative filtering, data about products purchased by users, as well as ratings and interactions with products (if available) are used. This data is organized into a matrix of users and products, where rows represent users and columns represent products, with the corresponding values indicating the level of user interest, such as purchases or ratings (Tareq et al., 2020).

The server component is implemented using the Flask framework, which provides a RESTful API that allows clients (online stores) to send requests to generate referrals. When a user visits a page, the client sends a request containing relevant user information (purchase history,

demographic data, etc.), and the server generates recommendations using K-Means clustering and collaborative filtering (Sarvar et al., 2001). The results are then sent back to the user in the form of a JSON object containing a list of recommended products.

The client component is implemented using basic web technologies (HTML, CSS, JavaScript). Its primary function is to send user data to the server and display the received recommendations in the form of dynamically generated product cards. Additionally, the client interface facilitate further user interaction with the system, such as product browsing and rating (Candillier et al, 2007).

System testing includes several stages:

- **Functionality testing:** All basic system functionalities are tested, including the generation of recommendations and interactions between the server and client components. Tests include checking the accuracy and relevance of recommendations based on the user's purchase history.
- **Performance evaluation:** Metrics such as precision, recall and F1-score are used to evaluate the accuracy of recommendations. Moreover, the response time of the system is tested in real conditions, in order to ensure that the recommendations are generated in the shortest period of time.
- **User Interface Testing:** Tests are conducted with real users to ensure that the user interface is easy to use, and that the referral process is clear and intuitive. User feedback is used to further improve the interface design.

During the implementation of the system, several technical challenges were identified and addressed to enhance system performance and user satisfaction:

- **Improving recommendation accuracy:** One of the biggest challenges was achieving satisfactory recommendation accuracy. By combining K-Means clustering and collaborative filtering, the accuracy is improved, but there is still a need for additional parameter optimization (number of clusters, selection of filtering metrics).
- **Management of large data sets:** To ensure efficient processing of large-scale user and product data, optimized search and data filtering algorithms have been implemented. Techniques such as batch processing (splitting data into mini-batches) and parallel data processing were introduced to improve computational performance and reduce processing time..
- **Scalability of the system:** To support a growing number of users and products, the system was designed with scalability in mind. Caching mechanisms for recommendation results and a load balancing strategy on the server side were implemented. This allows system scalability without losing performance.

Through these challenges, the system has been gradually optimized to provide a better user experience and faster referral generation.

CONCLUSIONS

This paper presented an implementation of a recommender system in an online store, using a combination of K-Means clustering based on association rules and collaborative filtering to generate personalized product recommendations to users. Through data analysis and algorithm implementation, the system has achieved significant success in improving the accuracy of recommendations, especially in cases where users have similar purchase histories. By using K-Means clustering to group users based on the similarity of their purchases, and collaborative filtering to recommend products based on the behavior of other users, the system successfully provides relevant recommendations.

Although the implementation of the system gives satisfactory results, there are also challenges, especially related to the cold start problem, when new users do not have enough data for accurate personalization of recommendations. In future, improvements are possible in the form

Radulović, D., & Blagojević, M. (2025). Design of recommender systems in e-commerce. *STED Conference 14*(2), 223-228.

of using more advanced algorithms, such as deep learning, and additional data sources that would enable even more precise and effective personalization.

Further research can focus on the optimization of existing algorithms, the integration of new technologies and the analysis of new methods that will enable a better user experience and greater accuracy of recommendations. Moreover, the introduction of real-time data analysis can contribute to faster and more accurate data processing, which will further improve the performance of the recommender system.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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***ENGINEERING, TECHNOLOGY AND
MATERIALS
INŽENJERSTVO, TEHNOLOGIJE I MATERIJALI***

SENSORY PROPERTIES OF JANJ CHEESE WITH THE ADDITION OF SELECTED PLANT SPECIES

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ABSTRACT

In many countries, cheese is a highly valued dairy product that, due to its high nutritional value, is recommended in the regular diet of every individual. Cheeses made by the traditional method using indigenous technologies are especially valued and represent the culture and tradition of some country. Janj cheese has been produced by such a traditional technology and it is the research subject of this study. The aim of this study was to examine the influence of the addition of selected plant species (*Origanum vulgare*, *Ocimum basilicum*, *Petroselinum crispum*, *Rosmarinus officinalis* and *Allium schoenoprasum*) at concentrations of 0.5% and 1% on the sensory properties of Janj cheese. A team of five evaluators performed sensory analysis of the tested cheese samples using a 5-point scoring system (1 = very considerable deviation from expected quality to 5 = no deviation from expected quality) to assess appearance, color, odor, taste, and texture. The addition of selected plants gave positive results and had statistically significant ($p < 0.05$) effects on the sensory properties of the tested cheeses. The highest scores were given to samples with *Origanum vulgare* and *Allium schoenoprasum* in both batches, i.e., with both concentrations (0.5 and 1%), and therefore the production of this type of cheese is recommended with the addition of these plant species.

Keywords: sensory properties, Janj cheese, plant species.

INTRODUCTION

Cheese is a food product that represents a complex combination of tradition and science, where specific milk processing techniques result in a product rich in nutritional value and characterized by unique sensory properties. It is not only a valuable staple food, but in recent times has become a product of high gastronomic value, particularly in countries with high living standards, where its consumption is steadily increasing (Popović-Vranješ, 2015).

Cheeses produced by traditional, indigenous technologies are especially appreciated, as they reflect the culture and heritage of a given country. These cheeses offer not only nutritional benefits but also cultural identity, preserving traditional production methods and the specific microclimatic conditions of their regions (Dozet & Mačej, 2006; Keskin & Dağ, 2020; Cardin et al., 2022), and they represent an important part of the gastronomic and cultural heritage of specific areas (Montel et al., 2014; Kochetkova et al., 2023). These cheeses are typically produced from the milk of local animal breeds using traditional methods passed down through generations. Such cheeses retain distinctive sensory properties as well as microbial biodiversity crucial for fermentation and ripening. They are commonly named after their place of origin, and many cities and regions have gained recognition precisely because of the cheeses bearing their names.

Indigenous cheeses have long played a vital role in the diet of local populations. Facing the risk of disappearance due to mass industrial production, traditional cheeses in many countries had

to be protected—France and Italy being countries with a long-standing tradition in this regard. In Bosnia and Herzegovina, several authors have contributed to the preservation and promotion of traditional dairy products through research and the affirmation of indigenous production technologies and traditional cheeses (Dozet, 2004; Bijeljac & Sarić, 2005; Dozet & Maćej, 2006). Production and consumption of these cheeses mostly continue to take place within rural households, with only a few indigenous products represented in industrial production (Bijeljac & Sarić, 2005).

Traditional cheeses are typically made from raw, unpasteurized milk, with or without the use of dairy cultures, and using natural rennet and herbs, involving considerable manual labor. Such cheeses are more difficult to produce under industrial conditions and differ from industrial cheeses in taste, aroma, and texture. They tend to have more complex and intense flavor and aroma profiles (Kalit, 2015). Janj cheese, which is the subject of this study, is made using one such traditional method preserved in households of the Šipovo municipality. Janj braided cheese is a unique product originating from the Janj region, produced from unpasteurized milk without any additives, and requiring approximately 12 liters of milk per kilogram of cheese. It is made in small rural households, where the production process is maintained through generations and primarily takes place within family units. This specific technology is most often practiced by younger women who traditionally inherit the knowledge of cheese production. The significance of this cheese is further enhanced by its production in the unpolluted ecological environment of Mount Vitorog and its surrounding pastures, which contributes to the unique quality of the milk and final product.

Today's market is increasingly saturated with products containing aromatic herbs, and a growing variety of plant species are being used in the production of cheese and other dairy products. These additions aim to develop new flavors, enhance aroma, and improve the nutritional and functional value of the products (Foda et al., 2010; Oraon et al., 2017; Alexa et al., 2018; Sukhikh et al., 2019; El-Sayed & Youssef, 2019; Arkan et al., 2024).

Different plants or their extracts can be used in the production of various dairy products in different ways: added directly to the curd, mixed into the cheese near the end of the production process before molding, or used to coat the cheese surface (Josipović et al., 2016). Herbs significantly enrich the diversity of flavors, aromas, and textures of cheese, increasing their appeal to consumers. Their specific aromas can make a cheese distinctive and recognizable (Kalit, 2015). Given the importance of traditional cheeses and the growing use of plant-based additives in dairy production, the aim of this study was to examine the influence of the addition of selected plant species (*Origanum vulgare*, *Ocimum basilicum*, *Petroselinum crispum*, *Rosmarinus officinalis*, and *Allium schoenoprasum*) on the sensory properties of Janj cheese.

MATERIAL AND METHODS OF WORK

The cheese samples used in this study were produced in a rural household in the village of Lipovača, located in the municipality of Šipovo, which has been engaged for many years in the production of milk, Janj cream (kajmak), and Janj braided cheese. Analyses of the final products were conducted at the Faculty of Technology, University of Banja Luka.

For the purposes of this research, two batches of six cheese samples were produced (a total of twelve samples). Each batch included one control sample without additives and five samples with the addition of different plant species: oregano (*Origanum vulgare*), basil (*Ocimum basilicum*), parsley (*Petroselinum crispum*), rosemary (*Rosmarinus officinalis*), and chives (*Allium schoenoprasum*). In the first batch, the concentration of plant additives was 0.50% relative to the cheese mass, while in the second batch it was 1.00%. For research purposes, the original cheese-making method was slightly modified: instead of shaping the cheese into the traditional braid, it was formed into a rolled shape incorporating the respective plant additives.

Following the evening milking, the milk was filtered and left to stand at room temperature overnight (14 hours). The milk's readiness for coagulation was assessed by heating 100 mL in a small metal container and observing characteristic changes, such as curd formation and whey separation. Once readiness was confirmed, the milk was heated to 38 °C, and 60 mL of rennet was added, corresponding to 0.2% of the total milk volume (30 L). The container was then left in a

warm place for 20 minutes to allow coagulation. Afterward, the temperature was raised to 50 °C, and the coagulated mass was gently stirred with a spoon for 10 minutes to cut the curd.

When the curd began to separate, the cheese mass was hand-pressed against the container walls for 10 minutes to expel the whey. The temperature of the whey at this stage was 48 °C. This step is essential for achieving the desired elasticity of the cheese mass. The curd was then gradually removed from the whey and further pressed to eliminate excess liquid. Each portion of the cheese mass was weighed (500 g) and manually flattened on a flat surface to a thickness of 1 cm. Salt was evenly distributed over the surface at a concentration of 1.50%, while plant additives were added in quantities of 0.50% for the first batch and 1.00% for the second batch (Table 1). For this purpose, commercially available, packaged, and crushed dried herbs (KOTANYI GmbH, Wolkersdorf, Austria) purchased from a local store were used. The finished cheese rolls were placed on an inclined surface for 30 minutes to allow excess whey to drain. Afterward, the cheese was wrapped in plastic film, cooled to +4 °C, and stored at the same temperature until analysis.

Table 1. Type and concentration of herbs in the tested samples.

	Sample	Plant species	Concentration (%)
Batch 1	1.1	-	-
	1.2	Oregano (<i>Origanum vulgare</i>)	0.50
	1.3	Basil (<i>Ocimum basilicum</i>)	0.50
	1.4	Parsley (<i>Petroselinum crispum</i>)	0.50
	1.5	Rosemary (<i>Rosmarinus officinalis</i>)	0.50
	1.6	Chives (<i>Allium schoenoprasum</i>)	0.50
Batch 2	2.1	-	-
	2.2	Oregano (<i>Origanum vulgare</i>)	1.00
	2.3	Basil (<i>Ocimum basilicum</i>)	1.00
	2.4	Parsley (<i>Petroselinum crispum</i>)	1.00
	2.5	Rosemary (<i>Rosmarinus officinalis</i>)	1.00
	2.6	Chives (<i>Allium schoenoprasum</i>)	1.00

Sensory properties and cheese quality were assessed using descriptive sensory analysis, a method that quantitatively evaluates multiple quality attributes of food products. Sensory evaluation was conducted by a panel of five assessors for each production batch. The sensory attributes evaluated included appearance, color, odor, taste, and texture, using a scoring system on a scale from 1 to 5 (1 = significant deviation from expected quality; 5 = no deviation) (BAS ISO 22935-2:2011; BAS ISO 22935-3:2011).

The results of all measurements were processed using Microsoft Excel 2013 and IBM SPSS Statistics 22.0 for Windows (Armonk, NY, United States). The data obtained from analyses conducted in this study are presented as mean values of individual results from three randomly selected product samples $\pm$ standard deviation (SD). The significance of differences between arithmetic means was determined by one-way analysis of variance (One-way ANOVA), followed by the Tukey HSD multiple range test, and expressed at a 95% confidence level ($p < 0.05$).

RESULTS AND DISCUSSION

The addition of selected plant species led to measurable changes in the sensory profile of Janj sir, affecting all evaluated characteristics. These variations highlight the importance of both the type of herb and its compatibility with the cheese in shaping overall sensory quality.

Table 2 presents the average values of the sensory analysis of the tested cheese samples, confirming statistically significant differences between the samples for all evaluated parameters ($p < 0.05$). The sensory evaluation included the following attributes: appearance, color, odor, taste, and texture, which are key sensory characteristics relevant to the acceptability of dairy products. The assessment of cheese appearance was conducted through visual inspection prior to consumption or preparation, considering color uniformity, surface consistency, the presence of

larger curds, and overall textural structure. Appearance represents a fundamental multimodal stimulus that strongly influences consumer expectations and can dominate the perception of other sensory modalities, especially taste and odor (Budimir et al., 2004). The color of fresh cheese should be homogeneous and light white, which indicates a proper technological process and the absence of contamination or undesired reactions (Mandić & Perl, 2006). Deviations in color may signal the presence of undesirable substances or inadequacies in the technological procedure, potentially compromising the safety and quality of the product (Fox et al., 2017).

Samples 1.1 and 2.1, produced without the addition of plant species and serving as control samples for the first and second batches, exhibited optimal sensory characteristics. Based on the conducted sensory evaluation, these control samples met relevant quality standards and received the highest possible scores from evaluators, without significant deviations, confirming the consistency and high sensory quality of the base product.

The tested cheese variant enriched with 0.50% oregano received lower scores for appearance and color (4.00), which can be attributed to uneven color distribution and non-uniform dispersion of the oregano additive. However, odor, taste, and texture were rated with the maximum score (5.00), indicating that the visual inconsistency did not adversely affect other sensory attributes. The inconsistency in the distribution of plant components negatively affected the visual quality of the product, resulting in a reduced overall sensory impression. Based on the sensory analysis results, an increased concentration of oregano above the tested 0.50% is recommended to achieve more homogeneous distribution and improved sensory characteristics of the product.

In the case of the tested cheese supplemented with 0.50% basil, the odor (4.25) and taste (3.50) were rated lower, although texture remained unaffected (5.00). This sensory profile indicates an insufficient synergy between the aromatic components of basil and dairy ingredients, which may result in a perception of weak aroma intensity and a “bland” taste. This suggests incompatibility of basil with the specific dairy matrix, indicating that basil may not be a suitable additive for this type of cheese.

The variant of the tested cheeses containing 0.50% parsley was characterized by lower scores for odor and taste (3.50 and 3.62, respectively), indicating a lack of sensory intensity, potentially due to the limited release of aromatic substances or their inadequate interaction with the dairy matrix. The intensity of odor and taste in cheeses often depends on the concentration and type of additive, as well as its ability to interact with core dairy components (Andriot et al., 2024; Pluta-Kubica et al., 2024).

The rosemary-enriched cheese variant at the same concentration exhibited a slightly rubbery and drier cross-sectional appearance, which was reflected in a marginally lower texture score (4.50). Furthermore, the uneven distribution of rosemary particles negatively affected both appearance and color (each scored 4.00), resulting in a non-uniform surface and noticeable color inconsistency. As uneven mixing and irregular additive dispersion can impair cheese texture (Tarakçı & Deveci, 2019), improving the homogeneity of rosemary incorporation is recommended to enhance sensory qualities, particularly in terms of appearance, color, and texture.

The tested cheese containing 0.50% chives received a suggestion for improved dispersion of the chive additive, which affected slightly lower scores for appearance (4.00) and color (4.00) compared to maximum values. Despite these moderate visual scores, this sample received the maximum score (5.00) for odor, taste, and texture, indicating strong sensory acceptance in these critical categories. The high odor and taste scores suggest that the added plant species contributed positively to the cheese’s aromatic and flavor profile without overpowering the characteristic dairy notes. The texture score of 5.00 further indicates that the additive was well integrated into the cheese matrix without adversely affecting mouthfeel, elasticity, or structural integrity.

The sensory analysis of the tested cheeses enriched with different plant species at a concentration of 0.50% indicates a significant influence of the distribution and compatibility of plant components with the dairy matrix on product quality. Uneven distribution of plant additives adversely affects the appearance, color, and texture of the cheeses, while inadequate synergy between plant aromas and dairy components may lead to a weaker expression of odor and taste. In certain cases, such as the use of basil, incompatibility was observed, which diminished the sensory

attributes of the product. To achieve optimal sensory properties, it is recommended to carefully adjust the concentration and ensure homogeneous spatial uniformity of the plant additives, as well as to consider the compatibility of specific plant species with the particular dairy formulation.

Table 2. Average sensory scores of Janj cheese with 0.50% plant species.

Sample	Appearance	Color	Odor	Taste	Texture
1.1	5.00 ^c ±0.00	5.00 ^c ±0.00	5.00 ^c ±0.00	5.00 ^b ±0.00	5.00 ^b ±0.00
1.2	4.00 ^a ±0.00	4.00 ^a ±0.00	5.00 ^c ±0.00	5.00 ^b ±0.00	5.00 ^b ±0.00
1.3	4.50 ^b ±0.00	4.50 ^b ±0.00	4.25 ^b ±0.29	3.50 ^a ±0.00	5.00 ^b ±0.00
1.4	5.00 ^c ±0.00	5.00 ^c ±0.00	3.50 ^a ±0.00	3.62 ^a ±0.25	5.00 ^b ±0.00
1.5	4.00 ^a ±0.00	4.00 ^a ±0.00	5.00 ^c ±0.00	5.00 ^b ±0.00	4.50 ^a ±0.00
1.6	4.00 ^a ±0.00	4.00 ^a ±0.00	5.00 ^c ±0.00	5.00 ^b ±0.00	5.00 ^b ±0.00

^{a-c} Means within the same column by different letters differ significantly at the 95% confidence level ($p < 0.05$)

Table 3 presents the sensory evaluation results for the second batch of Janj cheese samples. The sensory analysis of the tested cheese variant enriched with 1% oregano indicated the presence of a higher amount of the plant component in the cross-section of the product, which resulted in a lower score for the appearance parameter (4.00) compared to the maximum values. Additionally, the texture of the sample was rated lower (4.50), reflecting a slightly increased firmness relative to the desired sensory profile. Considering that sample 1.2. contained 0.5% oregano, while sample 2.2 had an increased concentration of 1%, where excessive presence of the herbal additive was observed, the recommendation based on the sensory evaluation results is to optimize the oregano concentration to an intermediate value of 0.75%. This adjusted concentration is expected to contribute to improved homogeneity of distribution and enhanced visual and textural characteristics, while maintaining an acceptable overall sensory profile.

The basil-enriched tested cheese (1%) received a lower score for appearance (4.50), which can be attributed to the presence of a higher amount of the plant additive in the cross-section compared to the recommended quantity. Nevertheless, the odor and taste remained characteristically “bland,” with a score of 4.50 and 3.50, respectively. This aligns with the sensory profile of the 0.5% basil sample from the first batch, indicating a consistent incompatibility of this plant species with the dairy matrix of the tested cheese. Based on the obtained results, the production of Janj cheese with basil at either tested concentration is not recommended due to an inadequate sensory profile.

The tested cheese sample with 1% parsley showed reduced scores for odor, taste, and texture (3.50; 4.00; 4.50). Sensory evaluation indicated a weakly expressed aroma and flavor, despite the higher quantity of the additive, while the texture was rated lower due to a less desirable and more difficult cross-section. A similar sensory profile was observed in sample 1.4 from the first batch, with 0.5% parsley. Based on these results, the use of fresh parsley instead of dried is recommended, as it is presumed that fresh parsley may contribute more significantly to aroma and flavor intensity, thereby improving the overall sensory quality of the product.

The cheese variant supplemented with 1% rosemary exhibited a slightly firmer texture (score 4.50) than optimal, likely as a result of the higher concentration of the additive. The elevated rosemary content also negatively influenced appearance and color (4.70 and 4.00, respectively), whereas odor and taste were rated highly (5.00 each), confirming a favorable aromatic profile.

The cheese sample containing 1% chives achieved maximum scores (5.00) for all evaluated sensory parameters. This sample represents the most acceptable product of the second batch, and compared to the first batch—where no sample besides the control received maximum scores—it can be concluded that sample 2.6 possesses the best overall sensory profile among all tested samples.

Among the second batch of samples, chives emerged as the most favorable additive, achieving the highest sensory scores across all evaluated parameters. Oregano also received positive assessments, particularly in flavor and aroma, although further optimization of its concentration is advised. In contrast, basil consistently demonstrated poor integration with the

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dairy matrix, while parsley yielded weak aroma and flavor expression. Rosemary contributed positively to aroma but slightly compromised texture and appearance at higher concentrations. Based on the overall sensory impressions, the additives can be ranked in the following order of acceptability: chives, oregano, rosemary, parsley, and basil. Consequently, further development of Janj cheese with the addition of chives and oregano, at precisely optimized concentrations, is recommended to achieve superior sensory quality and consumer acceptance.

Table 3. Average sensory scores of Janj cheese with 1% plant species.

Sample	Appearance	Color	Odor	Taste	Texture
2.1	5.00 ^a ±0.00	5.00 ^b ±0.00	5.00 ^b ±0.00	5.00 ^b ±0.00	5.00 ^b ±0.00
2.2	4.00 ^a ±0.00	5.00 ^b ±0.00	5.00 ^b ±0.00	5.00 ^b ±0.00	4.50 ^a ±0.00
2.3	4.50 ^b ±0.00	5.00 ^b ±0.00	4.50 ^b ±0.00	3.50 ^a ±0.00	5.00 ^b ±0.00
2.4	5.00 ^c ±0.00	5.00 ^b ±0.00	3.50 ^a ±0.00	4.00 ^a ±0.00	4.50 ^a ±0.00
2.5	4.70 ^{b,c} ±0.00	4.00 ^a ±0.00	5.00 ^b ±0.00	5.00 ^b ±0.00	4.50 ^a ±0.00
2.6	5.00 ^a ±0.00	5.00 ^b ±0.00	5.00 ^b ±0.00	5.00 ^b ±0.00	5.00 ^b ±0.00

^{a-c} Means within the same column by different letters differ significantly at the 95% confidence level ($p < 0.05$)

The utilization of selected plant species in the dairy industry represents an increasingly important approach to enhancing the quality of dairy products, particularly cheeses. Through their bioactive compounds, herbs not only enrich the sensory profile of dairy products but also exhibit notable antioxidant properties, contributing to improved product stability and extended shelf life (Sagun et al., 2006; Lee et al., 2016; Ebid et al., 2024). In this context, research aimed at identifying the optimal concentrations and types of plant additives plays a key role in the development of functional and high-quality dairy products.

According to Josipović et al. (2015), the incorporation of herbs in cheese production significantly enhances sensory characteristics, increases microbiological stability, and prolongs shelf life, while also improving the nutritional value of the product. Cheeses enriched with herbal additives such as red pepper, parsley, garlic, lavender, dill, and chives exhibit higher biological and nutritional value as well as favorable sensory properties. These improvements are primarily attributed to the presence of antioxidant and antimicrobial substances, which vary in concentration among different plant species.

Among traditional Croatian cheeses, fresh cheese produced from raw milk, such as Janj cheese, is particularly notable. This type of cheese requires stringent hygienic standards due to its perishable nature. To extend its shelf life, the use of ground red pepper has been introduced as a natural preservative and flavor enhancer (Josipović et al., 2015).

Alijagić et al. (2009) reported that the addition of culinary herbs has a minimal effect on the physico-chemical properties of dairy products, which is consistent with the findings of the present study. Sensory evaluation demonstrated a positive impact of herbal additives, with the highest scores observed in samples supplemented with oregano and chives at both tested concentrations (0.5% and 1%), indicating the potential of these plant species for further product development. However, it is important to note that excessive concentrations of herbal additives may adversely affect the sensory attributes of the final product. Previous studies (Tarakçı, 2004; Tarakçı & Kuçukoner, 2006) suggest that a concentration of approximately 1% represents an optimal level for achieving the most favorable sensory profile in cheeses.

CONCLUSIONS

Based on the conducted research, it was confirmed that Janj cheese can be successfully produced using a modified technological process incorporating the addition of various plant species. The experimental samples of Janj cheese, supplemented with oregano, basil, parsley, rosemary, and chives at concentrations of 0.50% and 1.00%, demonstrated that both the type and concentration of the added herbs had a statistically significant impact on the sensory attributes of the products ($p < 0.05$). Analysis of the overall sensory scores supports the recommendation to produce Janj cheese with the addition of chives and oregano, as these samples achieved the most favorable sensory profiles.

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The findings of this study carry important implications for the advancement of Janj cheese production, confirming the feasibility of enhancing a traditional product by incorporating herbal additives without compromising its sensory quality. The inclusion of herbs such as chives and oregano not only improves flavor and aroma but also adds market value in line with contemporary consumer preferences for natural and functional foods. This strategy may encourage diversification within the traditional cheese sector, support the preservation of local food heritage, and foster rural development through improved competitiveness and product distinctiveness.

Furthermore, these results provide a foundation for future research focused on optimizing the technological parameters involved in Janj cheese production with herbal additions, as well as on evaluating the effects of various herb species and concentrations on the physicochemical and microbiological properties of the product. Implementing such innovations in traditional dairy processing can contribute to the development of functional dairy products with improved sensory and nutritional profiles, ultimately enhancing the market potential of Janj cheese both domestically and internationally.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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IMPACT OF THAWING METHODS ON THE PHYSICOCHEMICAL AND NUTRITIONAL PROPERTIES OF BEEF MEAT

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ABSTRACT

This study aimed to examine the impact of various thawing methods (refrigerator, room temperature, and microwave oven) on the physicochemical and nutritional properties of beef meat (*Longissimus dorsi*). The following analyses were performed: weight loss, water content, ash, fat and protein content, water-holding capacity, colour, texture, water activity (a_w), pH value, and mineral composition. The results indicated that the thawing method significantly affects meat quality ($p < 0.05$).

The highest weight loss was recorded in samples thawed in a microwave oven (2.36%), while the lowest was in samples thawed in the refrigerator (0.81%). The highest water content was found in meat thawed in the refrigerator (74.99%), and the lowest was in samples thawed at room temperature (74.42%). The meat thawed at room temperature had the lowest water-holding capacity and the highest fat content. Colour changes were noted in all treatments, showing a decrease in lightness (L^*) as well as in a^* and b^* values, except for microwave-thawed samples. The highest texture firmness was measured in samples thawed in the refrigerator (4.34 kg). Water activity and pH levels increased after thawing in all treatments. Mineral content varied between fresh and thawed samples, with certain minerals showing notable deviations.

It was concluded that the slow defrosting method (at refrigerator temperature) best preserves the nutritional quality of beef meat.

Keywords: thawing methods, beef meat, quality, nutritional properties

INTRODUCTION

Freezing preservation is the most common method of food preservation. It can extend the shelf-life of food at subzero temperatures by removing large amounts of water from the solute phase to inhibit chemical, microbial, physical, and other reactions (Saki et al., 2023). Compared to other preservation methods, freezing is an important means to maintain the nutritional value and organoleptic properties of meat during processing, storage and transportation (Gan et al., 2022). Understanding the mechanism of ice formation is very important to improve the quality of frozen foods. The method is based on converting water in the form of ice crystals and lowering the temperature, which can stop all chemical, biochemical, and microbiological processes (Lovrić et al., 2003). The transition water to ice, simultaneously increase in the concentration of dissolved substances, and affects the reduction of water activity in food (Delgado & Sun, 2007), by reducing the activity of water below 0.7 when the metabolic activity of most microorganisms is significantly decreased or completely stopped (Nesvadba, 2008).

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The formation of ice during the freezing process leads to both physical and chemical changes in the product (Li et al., 2018). The intensity of these changes is largely influenced by the freezing rate, storage conditions, and the thawing method (Muela et al., 2012; Zequan et al., 2019). When freezing occurs slowly, fewer crystallization centers are formed, mainly in the intercellular spaces. The extended time required for ice crystal formation allows more water to be drawn from muscle fibers, resulting in larger crystals. Rapid freezing results in a greater number of crystallization centers forming both between and within muscle cells, the shorter freezing time limits water migration, and producing smaller crystals. Ultra-rapid freezing of meat generates a high number of very small ice crystals, primarily located inside the muscle fibers (Vuković, 2012; Živković & Stajić, 2016).

Before use, most frozen foods need to be thawed after being frozen and stored in that state. Thawing is the reverse process of freezing (Nesvadba, 2008). There are various methods for thawing frozen meat, and the most common traditional techniques include thawing in a refrigerator, in cold water, at room temperature, or using a microwave oven. In addition to these, modern thawing methods have been developed, such as high-pressure thawing, acoustic thawing, thawing by electro-heating (Akhtar et al., 2013), ultrasonic thawing and infrared thawing (Gan et al., 2022). During the thawing process, meat is often accompanied by protein degradation, fat oxidation, color deterioration and reduced water holding capacity due to the melting of ice crystals (Gan et al., 2022). Therefore, in order to improve the quality of thawed meat, it is important to adopt appropriate thawing methods (Alonso et al., 2016).

This paper aims to examine the influence of different thawing procedures (at room temperature, in the microwave oven, and in the refrigerator at 4°C) on the physico-chemical properties of beef meat.

MATERIAL AND METHODS OF WORK

Analyses were performed on a sample of fresh beef meat (*Longissimus dorsi*) obtained from the market. The pieces were cut into 2.0 cm thick slices, packed in polyethylene bags and, after marking, froze at a temperature of -20°C. After freezing the samples were stored at -20 °C for 24 h, until the analysis. Before the analysis, the samples were thawed in one of the following ways: 2 hours at 20°C (at room temperature), thawing in a microwave oven (2450 MHz, 700 W) to the temperature of 4°C in the center of the piece of meat, and 10 hours at 4°C (in a refrigerator). All analyses were performed on fresh (unfrozen) samples, as well as on samples after freezing and after certain defrosting treatments of the samples thawing using different methods.

The freezing/thawing weight loss was determined by measuring the weight of fresh meat samples before freezing and after thawing. The moisture content was determined by drying (BAS ISO 1442:2007), ash by incineration at 550°C (BAS ISO 936:2007), fat by extraction (BAS ISO 1443:2007), and protein by Kjeldahl method (BAS ISO 937:2007). The compression method (Grau & Hamm, 1953) was used to measure the water-binding capacity of beef meat, using the digital planimeter (Placom KP-92N, Koizumi, JAPAN). Water activity (a_w) was measured by direct readings in Aw Meter (Novasina LabMaster-AW 1119971). The pH value was measured by inserting a pH meter (Hanna instruments, HI 2211) into aqueous meat extract. Instrumental colour measurement was performed using a spectrophotometer CM-2600d (Konica Minolta Sensing Inc., Japan), colour parameters, expressed as CIE L^* , a^* and b^* values, were determined as respective indicators of lightness, redness, and yellowness. Texture was determined using a Texture Analyzer TA.XT plus (Stable Micro Systems) with Warner-Blatzler knife cutting blade which measures the shear force needed to cut the sample (1×1 cm). The meat samples were prepared according to Mandić et al. (2013).

Sample preparation for mineral analysis was carried out by digestion with a mixture of acids, and an Optical Emission Spectrophotometer (ICP OES Optima 8000, Perkin Elmer) was used to determine the mineral content (Savanović, 2021).

All analyses were performed with three repetitions, and instrumental colour and texture measurement with 10 repetitions.

Statistical processing of the obtained results was performed using the Microsoft Excel 2013 software package and the IBM SPSS Statistics 22.0 computer program for Windows (Armonk, NY, United States). The results obtained in this paper are presented as mean values $\pm$ standard deviation (SD). The significance of differences between arithmetic means was determined by analyzing the variance with one independent variable (One way ANOVA) and multiple interval tests (Tukey Post-hoc test) and expressed with 95% probability ($p < 0.05$).

RESULTS AND DISCUSSION

Weight loss and chemical composition of beef meat are presented in Table 1. As can be seen from the results, the thawing method has a statistically significant influence ($p < 0.05$) on the weight loss and chemical composition of beef meat. Weight loss is an important change that occurs during freezing and thawing of products. The analysis showed that significant weight loss was observed in the meat thawed in the microwave (2.36%). This result differs significantly from the results obtained for meat thawed at room temperature (1.32%) and refrigerator temperature (0.81%). The formation of ice during freezing leads to physical and chemical changes in the product. The main physical effects include mechanical damage, changes in muscle fibers and cell membranes, water migration, ice recrystallization, and moisture loss during thawing (Sučić et al., 2010; Savanović et al., 2017; Park & Kim, 2024). The amount of water released during thawing depends on the characteristics of the meat (pH value, presence of fatty tissue), the speed and method of freezing, storage conditions and duration, and the thawing technique (Vuković, 2012). Rapid freezing is characterized by the formation of a large number of small crystals, and the amount of water during thawing is minimal. The larger the crystals formed during freezing lead to greater the damage to the cell, and the greater the loss of tissue fluids during the thawing of the meat. The primary cause of such changes is the formation of large ice crystals, which mechanically damage tissues, and these damages are irreversible (Savanović, 2021).

Table 1. Weight loss and chemical composition of beef meat.

		Weight loss (%)	Water (%)	Protein (%)	Fat (%)	Ash (%)
Thawing method	fresh meat		75.79 ^a $\pm$ 0.09	21.95 ^a $\pm$ 0.06	0.21 ^a $\pm$ 0.01	1.19 ^a $\pm$ 0.03
	room temperature	1.32 ^a $\pm$ 0.02	74.42 ^b $\pm$ 0.09	22.11 ^b $\pm$ 0.06	0.38 ^b $\pm$ 0.01	1.25 ^b $\pm$ 0.01
	microwave oven	2.36 ^b $\pm$ 0.04	74.43 ^b $\pm$ 0.03	23.34 ^c $\pm$ 0.03	0.36 ^b $\pm$ 0.00	1.31 ^c $\pm$ 0.01
	refrigerator	0.81 ^c $\pm$ 0.02	74.99 ^c $\pm$ 0.06	22.14 ^b $\pm$ 0.03	0.25 ^c $\pm$ 0.02	1.21 ^{ab} $\pm$ 0.02

^{a-c} Mean values with a different letter in the same column are statistically significantly different from 95% probability ($p < 0.05$)

The water content in fresh beef ranges from 60% to 75%, depending on the part of the meat. The water content is greatly influenced by fat content, with their levels in meat being inversely related (meat with less fat has higher water content) (Savanović, 2021). Fresh samples of analyzed beef meat had an average water content of 75.79% before freezing. After thawing, the highest water content was in those thawed in the refrigerator (74.99%), followed by the samples thawed in the microwave oven (74.43%), and the lowest water content was found in the samples thawed at room temperature (74.42%). Analyzing Brazilian frozen beef imported into Algeria, Ziani et al. (2018) report similar values of water content (average 75.25%).

During thawing, some water is released from the food as it transitions from a solid to a liquid state. This fluid loss occurs due to ice crystal formation during freezing and the muscle tissue's reduced ability to reabsorb the fluid when thawed (Delgado & Sun, 2007; Sučić et al., 2010; Savanović et al., 2019). The quality of thawed food is influenced not only by the freezing speed and storage conditions but also by the thawing rate. Slow thawing, particularly in meat, allows water to reattach to proteins, reducing fluid loss. Additionally, when thawing occurs slowly at lower ambient temperatures, microbial activity is somewhat suppressed. As a result, slow thawing tends to have a less negative effect on food quality (Vereš, 2004).

By analyzing the protein content, it was determined that the fresh beef samples, before freezing, had an average protein content of 21.95%. After thawing, due to the loss of some water, the protein content increased slightly in samples thawed in a microwave oven (23.34%), while it decreased in samples thawed in a refrigerator (22.14%) and at room temperature (22.11%). Similar values were obtained by Ziani et al. (2018).

During freezing and storage, changes occur in proteins (denaturation and oxidation, modification of the amino acid chain), cause a decrease in the functional properties of proteins and affect the meat quality after thawing (Savanović & Grujić, 2017, Çalışkan Koç et al., 2025). Sabow et al. (2020) state that the crude protein content in frozen meat is expected to be lower than in fresh meat because denaturation and loss in gelatin caused by extended frozen storage also due to proteolysis.

Fat content in fresh beef meat was 0.21%, and after thawing ranged from 0.25-0.38% (thawing in refrigerator and at room temperature, respectively). Çalışkan Koç et al. (2025) consider that the higher fat content in meat has been linked to lower electrical conductivity, leading to longer thawing time. It has been suggested that different factors may affect fat content in beef cattle meat such as breed, rearing system and nutritional supply, weight at slaughter, gender and for the same animal according to the piece recovered (Ziani et al., 2018; Sabow et al., 2020).

Ash content in analyzed samples ranged from 1.21-1.31% in beef meat thawed in a refrigerator and in microwave, respectively, and in fresh meat 1.19%. The present results were similar with literature data (Ziani et al., 2018; Ngom et al., 2022). The amount of minerals in meat depends, above all, on the age and type of animal, feeding, and breeding method (Savanović, 2021).

Table 2 show results for water-holding capacity (WHC), water activity and pH value of examined beef meat. The thawing methods had a statistically significant influence ($p<0.05$) on WHC of beef meat after thawing.

Table 2. Influence of thawing methods on water-holding capacity (WHC), a_w and pH value of beef meat.

		WHC (cm ²)	a_w	pH
Thawing method	fresh meat	1.31 ^a ±0.03	0.881 ^a ±0.001	5.77 ^a ±0.03
	room temperature	2.16 ^b ±0.01	0.883 ^a ±0.001	5.88 ^b ±0.06
	microwave oven	2.10 ^c ±0.02	0.883 ^a ±0.001	5.81 ^{ab} ±0.01
	refrigerator	1.59 ^d ±0.03	0.895 ^b ±0.001	6.03 ^c ±0.02

^{a-d} Mean values with a different letter in the same column are statistically significantly different from 95% probability ($p<0.05$)

In fresh meat WHC values was 1.31 cm², and after thawing ranged from 1.59-2.16 cm² (refrigerator and room temperature, respectively). Szmańko et al. (2021) reported that WHC value of fresh meat was higher than that of frozen meat. The meat thawed using slower thawing methods had a greater water-holding capacity and released less fluid during compression than meat thawed faster. The major water-holding carrier in muscles is myofibrillar proteins, due to their specific chemical structure (Rede & Petrović, 1997), and is an indirect measure of protein denaturation (Savanović & Grujić, 2017).

Values for a_w were 0.881 in fresh beef meat, 0.883 in samples thawed at room temperature and in microwave and 0.895 in the sample thawed in refrigerator. The melting of ice in the extracellular spaces causing an increase in water activity (Akhtar et al., 2013).

The pH value of fresh beef sample was 5.77, whereas those of beef samples thawed at room temperature, using a microwave oven, and in a refrigerator increased significantly to 5.88, 5.81, and 6.03, respectively ($p<0.05$). Ike et al. (2018) report pH value for beef from 5.1-6.2. Park and Kim (2024) attribute the rise in pH to amino acid leakage during prolonged thawing, noting that extended thawing damages muscle cells and leads to drip, which contributes to the increase. Variations in pH are likely due to glycogen breakdown into lactic acid and proteolysis, which

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increases free alkaline groups, and/or variations in muscle protein water-holding capacity, influencing the color, appearance, and shelf life of the meat samples (Wali et al., 2025).

Instrumentally measured color and texture parameters of fresh and thawed beef meat are presented in Table 3. The obtained results showed that thawing procedures had statistically significant effect ($p<0.05$) on the colour and texture of beef meat. The L^* value on the surface of the fresh meat sample was 43.53, and for thawed samples values were slightly lower, ranged from 42.12-43.31. There was an increase in the share of red (a^* value) and yellow colour (b^* value) in sample thawed in microwave compared to those measured on fresh meat. The color of meat depends on the concentration and state of myoglobin (Mb) and hemoglobin (Hb). The change in meat colour is a result of changes in the chemical state of myoglobin and the postmortem processes (changes in the muscles) (Savanović, 2021). Park and Kim (2024) consider that L^* values of beef samples significantly decreased when they were thawed in a refrigerator, in cold water, and at room temperature. Freezing and thawing affect on a^* value of meat samples due to myoglobin oxidation, increasing the temperature tended to increase myoglobin oxidation and discoloration in beef (Park & Kim, 2024).

Table 3. Instrumentally measured color and texture parameters of fresh and thawed beef meat.

		L^*	a^*	b^*	Texture (kg)
Thawing method	fresh meat	43.93 ^a ±0.79	12.06 ^{ab} ±0.79	10.49 ^{ab} ±0.57	3.22 ^a ±0.31
	room temperature	42.94 ^{ab} ±0.53	11.97 ^a ±0.87	10.26 ^{ab} ±0.89	4.01 ^b ±0.81
	microwave oven	43.31 ^a ±0.59	13.52 ^b ±0.90	11.75 ^a ±0.77	4.08 ^b ±0.84
	refrigerator	42.12 ^b ±0.64	11.74 ^a ±0.78	9.76 ^b ±0.57	4.34 ^c ±0.90

^{a-b} Mean values with a different letter in the same column are statistically significantly different from 95% probability ($p<0.05$)

The texture of thawed meat was harder than fresh meat sample, due to structural changes in the tissues. Fresh meat was the softest (3.22 kg), and the thawed meat had bigger hardness (4.01-4.34). Savanović (2021) considers that the increase in meat hardness after freezing occurs as a result of various physico-chemical changes in proteins and strengthening of the protein matrix. Results present by Park and Kim (2024) show that the beef sample thawed using a microwave oven had the maximum hardness, gumminess, and chewiness compared with those thawed using other methods. The increase in shear force within the muscle could result from differences in connective tissue content, sarcomere length, and muscle fiber size along its entire length (Stafford et al., 2024).

Table 4 shows the mean values of macroelements content in fresh and thawed samples of beef meat. Based on the obtained results, it was determined that there was statistically significantly difference ($p<0.05$) for some minerals (Na, P). The most dominant minerals in beef meat were phosphorus and potassium, ranged from 2715.07-2795.83 mg/kg, and 1391.86-1798.76 mg/kg, respectively.

Table 4. Content of macroelements (mg/kg) of fresh and thawed beef meat.

		P	K	Mg	Na
Thawing method	fresh meat	2795.42 ^a ±10.44	1572.94 ^a ±35.25	293.47 ^a ±0.60	164.50 ^a ±5.65
	room temperature	2719.61 ^b ±32.43	1735.12 ^a ±21.42	291.41 ^a ±10.11	745.44 ^b ±4.54
	microwave oven	2795.83 ^a ±15.44	1391.86 ^a ±8.68	293.43 ^a ±16.85	334.02 ^{ac} ±6.97
	refrigerator	2715.07 ^b ±36.61	1798.76 ^a ±48.59	292.26 ^a ±2.61	632.44 ^{bc} ±8.18

^{a-c} Mean values with a different letter in the same column are statistically significantly different from 95% probability ($p<0.05$)

The amount of Na and K from the collected fresh meat samples was analyzed by Wali et al. (2025) with ICP-OES were Na-508.81 mg/kg, and K-2994.13 mg/kg. The same authors state that age, breed, nutrition, birthplace, and other environmental factors can all have an impact on the mineral content of meat. Campo et al. (2024) report that Pyrenean beef is an excellent source of potassium, phosphorus, and zinc, and low in sodium. The same authors state highest values for K and P (352-404 mg/100g and 163-188mg/100g, respectively), and similar values Mg and Na (21-27 mg/100g, 40-66 mg/100g, respectively).

Based on the results shown in Table 5, the content of microelements in the fresh and thawed meat samples ranged as follows (mg/kg): zinc 164.40-215.96, calcium 51.21-70.56, iron 17.08-24.50, manganese 0.04-0.15 and copper 0.62-0.80. Some of analyzed minerals were below the detection limit (Se-2µg/L, Al, As, Hg-1µg/L). The significant differences (p<0.05) were observed in the concentration of Fe, Mn, and Cu. Sabow et al. (2020) report that Fe and Zn exhibited the highest concentrations in the two types of meat analyzed, compared to the other essential elements. The same authors state that muscles of cattle are the tissues where Zn is most likely to accumulate. Similar content of Ca and Fe report (Campo et al., 2024).

Table 5. Content of microelements (mg/kg) of fresh and thawed beef meat.

		Zn	Ca	Fe	Mn	Cu
fresh meat		164.40 ^a ±1.24	55.21 ^a ±2.09	19.20 ^a ±0.29	0.13 ^{ab} ±0.01	0.80 ^a ±0.08
Thawing method	room temperature	177.27 ^{ab} ±0.31	58.61 ^a ±3.02	18.37 ^a ±0.11	0.09 ^{ac} ±0.01	0.62 ^b ±0.03
	microwave oven	215.96 ^c ±8.03	70.56 ^a ±6.94	17.08 ^a ±0.08	0.04 ^c ±0.04	0.70 ^{ab} ±0.09
	refrigerator	193.97 ^b ±2.70	51.21 ^a ±3.12	24.50 ^b ±2.88	0.15 ^b ±0.01	0.72 ^{ab} ±0.02

^{a-c} Mean values with a different letter in the same column are statistically significantly different from 95% probability (p<0.05)

Concentrations of toxic metals (Hg and As) in fresh and thawed beef meat were below the limit of detection, and maximum limits of toxic metals permissible in red meat for EU countries for mercury is 1.0 mg/kg and for arsenic 0.3 mg/kg (Nkosi et al., 2021).

CONCLUSIONS

Freezing meat causes certain major or minor irreversible physical and chemical changes in food. While freezing enhances the meat's sustainability and extends its shelf life, it also leads to alterations due to the formation of ice crystals. Additionally, the method of thawing can significantly influence the quality of thawed meat.

By analyzing the data obtained in this study, the thawing method significantly affects the physical and chemical properties of beef meat. Microwave thawing caused the highest weight loss, while refrigerator thawing preserved moisture best and resulted in the least damage. Besides changes in the basic chemical composition, different thawing procedures also impact the colour, texture, pH value, and water activity of thawed beef. Mineral content also varied with thawing method.

The method used for thawing plays a crucial role in determining meat quality. Based on the results, it can be concluded that slow thawing of beef (at refrigerator temperature) allows helps retain water and protein quality, reduces fluid loss, and maintains better pH and water activity levels. If food is thawed slowly, the ambient temperature remains low, which can inhibit microorganism growth.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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PHYSICO-CHEMICAL AND ANTIOXIDANT PROPERTIES OF COLD-PRESSED ARONIA JUICE

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ABSTRACT

Aronia, as a berry fruit rich in nutrients, represents a suitable raw material for obtaining cold-pressed juices. The chemical composition of aronia indicates the presence of a large amount of polyphenolic compounds and anthocyanins, which contribute to its antioxidant and antimicrobial properties. This study describes the process of producing cold-pressed juice from organically grown aronia (Organic Control System certified), which is frozen immediately after pressing without pasteurization and the addition of additives. Physico-chemical analyses included determination of acidity, pH value, dry matter content, and pectin content. Based on the analysis results of antioxidant properties, which involved determination of total phenols, flavonoids, FRAP, DPPH, and ABTS tests, the study showed that cold-pressed aronia juice has high antioxidant properties. Considering that aronia juice is cold-pressed, aimed at reducing the effects of elevated temperatures on the quality of aronia juice, without the addition of additives, preservatives, colors, sweeteners, etc., it can be said that its good antioxidant properties originate from the raw material, i.e., aronia berries.

Keywords: aronia, cold-pressed juice, antioxidant activity.

INTRODUCTION

The deciduous black-fruited shrub aronia (lat. *Aronia melanocarpa* L.) belongs to the rose family (lat. *Rosaceae*) and originates from eastern North America, including eastern Canada. Today, it is also cultivated in Eastern Europe (Bilić 2017). Aronia is grown both as an ornamental plant and for the high nutritional value of its berries, as well as their antioxidant properties and distinctive flavor. Aronia cultivation initially focused on its strong purple pigment resulting from high anthocyanin content, leading to its use as a natural coloring agent in the food and pharmaceutical industries. In the food industry, aronia is commonly processed into juices and syrups, while the fruit can be consumed raw, dried, or used in compotes, jams, wines, and liqueurs (Šnebergová et al. 2014).

The chemical composition of aronia varies significantly and depends on numerous factors, including genotype, degree of ripeness, climate conditions, harvest time, and fertilizer use. Aronia contains B-group vitamins, vitamin C, β -carotene, and significant amounts of dietary fibers, minerals, carbohydrates, and organic acids (Šnebergová et al. 2014).

Berry fruits represent a rich source of phenolic compounds and other bioactive components. Isolated bioactive components from aronia can contribute to human health. Aronia contains various polyphenols (proanthocyanidins, anthocyanins, flavonoids, phenols, and phenolic acids) with anti-inflammatory and antiviral properties (Bataraga and Valkovska, 2020).

The aim of this study was to produce cold-pressed juice from aronia grown in the Republic of Srpska and to investigate its physical-chemical and antioxidant properties.

MATERIAL AND METHODS OF WORK

For the production of cold-pressed juice, aronia grown in the area of the city of Prnjavor, located in the northwest part of the Republic of Srpska, was used. The aronia production at this household holds an organic production certificate (OCS - Organic Control System). Aronia berries were harvested at the stage of technological maturity. After harvest, all fruits that did not meet satisfactory quality standards were discarded, the berries were washed, and then cold-pressed to extract the juice. The obtained juice was packed into 0.5 L plastic bottles and frozen at -20°C. The juice was not pasteurized, and no sugar, preservatives, or any other additives were added. During analysis, after opening, the juice was stored in a refrigerator at 4°C.

Analysis of physico-chemical properties: Determination of dry matter content was performed refractometrically using a Leica Mark II Plus ABBE refractometer. pH value was measured using a pH meter Hanna Instruments HI-1122. Acidity and pectin content were determined according to the Regulation on Sampling and Methods of Chemical and Physical Analysis for Quality Control of Fruit and Vegetable Products, Official Gazette of the SFRY 29/83.

Antioxidant activity determination: The total phenolic content was determined using the modified method of Folin-Ciocalteu (Wolfe et al. 2003), and the content of flavonoids was determined using the method of Ordenez et al. (2006). The testing of antioxidant activity using the Ferric reducing/Antioxidant power (FRAP) assay was carried out in accordance with Banzie and Strain (1996); the 2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS) assay using the modified method of Re et al. (1999) and the 2,2- diphenyl-1-picryl-hydrazyl (DPPH) assay using the method of Brand-Williams et al. (1995) with some modification. A 0.1 mM solution of DPPH (1,1-diphenyl-2-picrylhydrazyl) in methanol was prepared. 1 mL of aqueous honey solution was mixed with 1 mL of DPPH solution. The mixture was left to stand for 30 min in the dark and absorbance was read spectrophotometrically at 517 nm. The results were expressed as µg of gallic acid (GA) /mg honey. All the chemicals and reagents used were of analytical grade.

RESULTS AND DISCUSSION

Table 1 shows the results of the analysis of the physico-chemical properties of cold-pressed aronia juice: acidity, pH value, dry matter content, and pectin content. The measured acidity in aronia juice was 10.29 g/L. Since the cold-pressed aronia juice was analyzed without any additions, it can be concluded that the acidity in the juice originates from the aronia berries. Aronia berries naturally contain about 1 to 1.5% organic acids, with the most prevalent being malic, tartaric, and citric acids (Šnebergová et al. 2014). Organic acids are a crucial component after sugars because their presence and composition affect sensory properties (Denev et al. 2018). Sosnowska et al. (2016) reported organic acid content ranging from 12.27 to 21.87 g/L in aronia juice, which are higher values compared to those obtained in this study.

Table 1. Physico-chemical analysis of cold-pressed juice.

Parameter	Aronia juice
Acidity (g/L)	10,29 ± 0,02
pH value	3,33 ± 0,02
Dry matter content (%)	19,23 ± 0,01
Pectin content (%)	0,16 ± 0,00

Aronia juice is an acidic product with a low pH value influenced by the content of organic acids. The measured pH value in cold-pressed aronia juice was 3.33, similar to the results reported by Bolling et al. (2015) measured pH values ranging from 3.15 to 3.45. Slightly higher values than those measured are reported by Tolić et al. (2017), who measured pH values ranging from 3.77 to 3.96, and Tolić et al. (2018), who reported pH values ranging from 3.54 to 3.92, as well as Sosnowska et al. (2016), who reported pH values from 3.42 to 3.72. Such low pH values indicate that aronia juice is an acidic product which, combined with its low sugar content, affects its consumer acceptability negatively (Tolić et al. 2018).

The dry matter of aronia fruits consists mainly of sugars, proteins, amino acids, and lipids (Sidor and Gramza-Michałowska 2019). The dry matter content in aronia juice was measured at 19.23%. Tolić et al. (2018) reported dry matter content ranging from 7.96% to 22.55%, while Tolić et al. (2017) reported values from 19.22% to 26.94%, which are similar to the measured results. Sidor and Gramza-Michałowska (2019) indicated dry matter content in aronia fruits from 17.9% to 26%, and in juice from 11.1% to 17.4%. Ochmian et al. (2012) reported dry matter content in fruits from 15.3% to 19.5%, of which soluble matter ranged from 14.2% to 18.7%. The dry matter content in aronia depends on the variety, fruit maturity, climatic conditions (Sidor & Gramza-Michałowska 2019), and soil composition where aronia is cultivated (Trenka et al. 2020).

Aronia fruits are moderately rich in pectins, with content ranging from 0.30% to 0.75% (Trenka et al. 2020). Adam and Versini (1996) note that pressing fruit juice removes most of the pectin substances, which are predominantly located in the fruit pulp. The pectin content in the analyzed juice is 0.16%, which is lower compared to the literature data reported for aronia fruits.

Table 2. Results of antioxidant activity.

Parameter	Aronia juice
Total phenolic content (mg GAE/L)	3468,80 ± 28,28
Total flavonoids content (mg GAE/L)	2786,19 ± 3,26
FRAP (mmol Fe ²⁺ /mL)	30,78 ± 0,06
DPPH (µg TE/mL)	1548,33 ± 11,23
ABTS (mg TE/mL)	0,89 ± 0,01

Table 2 presents the results of the antioxidant activity of aronia juice, where it can be seen that the content of total phenols in aronia juice was 3468.80 mg GAE/L. Tolić et al. (2017) state that the content of phenolic compounds in aronia depends on the harvesting season and climatic conditions, reporting values ranging from 8563.8 to 12055.7 mg GAE/L. Efenberger-Szmechtyk et al. (2020) report the content of total phenols in aronia fruit to be around 8615 mg GAE/L. These literature data indicate slightly higher values of total phenol content compared to the result obtained in this study. The reason for this could be the loss of certain components during fruit processing into juice. Jurikova et al. (2017) measured the content of total phenols in aronia juice ranging from 690 to 2560 mg GAE/L, which represents slightly lower values compared to the value obtained in this study. The high content of phenolic compounds in aronia juice is important as research confirms their significant impact on reducing plasma lipid peroxidation, scavenging free radicals, and replenishing antioxidant enzymes (Jurikova et al. 2017).

The content of flavonoids in aronia juice was 2786.19 mg GAE/L (Table 4.2). Tolić et al. (2017) measured flavonoid content in aronia juice ranging from 6994 to 9710 mg GAE/L and found significant differences depending on the harvest season. They also state that flavonoids represent the most abundant group of phenolic compounds in aronia, specifically from 79.2 to 87.5%. A large number of literature sources indicate that quercetin is the most abundant flavonoid in aronia (Denev et al. 2012).

The FRAP value for aronia juice is 30.78 mmol Fe²⁺/mL. Tolić et al. (2017) report FRAP values in aronia juice ranging from 128.2 to 179.5 mmol Fe²⁺/mL, which are higher compared to the values obtained in this study. The DPPH value in aronia juice is 1548.33 µg TE/mL, and ABTS is 0.89 mg TE/mL. There are few literature results for DPPH and ABTS expressed in the units used in this study, thus making comparison difficult.

CONCLUSIONS

Aronia represents a raw material increasingly used to produce various products, among which cold-pressed juices are often found. Based on the results presented in this study, it can be seen that aronia has extremely strong antioxidant properties and contains large amounts of phenolic compounds

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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EFFECT OF FREEZING ON PHYSICO-CHEMICAL, ANTIOXIDANT, AND SENSORY PROPERTIES OF HONEYDEW HONEY

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ABSTRACT

Freezing food slows down the physico-chemical and biochemical reactions in food. In honey, freezing is primarily used to delay or halt crystallization, reduce viscosity, and preserve nutritional components. However, low temperatures may influence the physico-chemical, antioxidant, and sensory properties of honey.

This study compares the properties of honeydew honey before and after freezing treatment. The analysis included the evaluation of physico-chemical parameters such as moisture content, water activity, pH value, acidity, hydroxymethylfurfural (HMF) content, diastase activity, sugar content, ash content, and electrical conductivity. Antioxidant properties were assessed by determining total phenolic and flavonoid content, as well as FRAP, ABTS, and DPPH assays, along with HPLC analysis. Sensory evaluation encompassed assessments of color, consistency and texture, odor, taste, and aroma.

The obtained results indicated a decrease in water activity and pH value after freezing, accompanied by an increase in acidity. HMF content and diastase activity exhibited only minor changes compared to the control sample. Additionally, an increase in total flavonoid content and higher FRAP and DPPH values were observed. HPLC analysis revealed elevated levels of catechin and malvidin in the treated sample. Sensory evaluation showed no significant differences in the taste and aroma of honeydew honey following the freezing treatment.

Keywords: honeydew honey, freezing treatment, antioxidant activity, sensory properties.

INTRODUCTION

Freezing food slows down, but does not stop, the physicochemical and biochemical reactions that lead to food spoilage (Rahman, & Velez-Ruiz, 1999). Hermetically sealed honey can be stored at freezing temperatures, as it is considered that this method allows for longer preservation, while having minimal impact on its physicochemical, antioxidant, and antimicrobial properties (Kędzierska-Matysek, et al., 2016).

Lower temperatures slow down chemical reactions in honey, which is particularly noticeable at temperatures below 0 °C (Kędzierska-Matysek, et al., 2016). In addition to halting microbiological growth, freezing temperatures aim to preserve all nutrients present in the food matrix (James, & James, 2014). However, frozen food undergoes changes in its physicochemical properties, most notably in pH value, viscosity, water activity, and redox potential (Rahman, & Velez-Ruiz, 1999).

Low temperatures slow down or completely inhibit the crystallization process in honey, reduce viscosity, and prevent the onset of fermentation (Kędzierska-Matysek, et al., 2016). Most types of honey contain a higher proportion of glucose compared to fructose, which may lead to spontaneous crystallization at room temperature, resulting in the formation of glucose monohydrate. In addition to the glucose-to-fructose ratio, the water content also influences honey

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crystallization. Conforti, et al. (2006) found that honey types with higher water content crystallized more at -20°C , which is the opposite of the results obtained at room temperature.

The aim of this study was to investigate the effect of low temperature on the physicochemical, antioxidant, and sensory properties of honeydew honey.

MATERIAL AND METHODS OF WORK

As the sample for the analysis was used honeydew honey from the territory of the Republic of Srpska, Bosnia and Herzegovina. The untreated honeydew honey was used as the control sample (C), as also reported in the study by Stojković, et al. (2021). The honeydew honey sample was subjected to freezing at temperature -18°C (sample T). The freezing process involved transferring the honey into plastic screw-cap tubes, followed by storage in a freezer. The honey remained frozen under these conditions until subsequent analysis. The experiment was carried out in triplicates.

The characteristics and satisfactory quality of all samples were assessed through an analysis of the following parameters: water content, diastase activity, HMF content, acidity, reducing sugars, saccharose, electrical conductivity as described by Ordinance on methods for control of honey and other bee products (Official Gazette of BiH no 37/2009, 2009). The pH was measured with a pH meter (Hanna Instruments HI-2211). All the chemicals and reagents used were of analytical grade.

The water activities of samples were analyzed at $25 \pm 0.2^{\circ}\text{C}$ by using the instrument LabMaster-aw (Novasina, Switzerland). The detection limit was $\pm 0.003 a_w$. Calibration was performed with saturated salt solutions in the a_w range of 0.2–0.6.

HPLC analysis: The chemicals and reagents used were of analytical grade. All the standards: catechin hydrate, gallic acid, malvidin, rutin, chlorogenic acid, benzoic acid, quercetin, caffeic acid, ferulic acid and naringenin were of purity $> 95\%$. Measurements were performed on HPLC agilent 1260 infinity (USA) equipped with DAD detector. The HPLC analysis of phenolics was conducted according to Hussein, et al. (2011) method with some modifications. Honey samples (10 g) were dissolved in 50 mL of deionized water and filtered through a membrane filter (Liofilchem, Italy) $0.20\ \mu\text{m}$. Chromatographic conditions: reversed phase column EC-C18, Poroshell-120 ($4.6 \times 50\ \text{mm}$, particle size $2.7\ \mu\text{m}$), the mobile phase 0.1% HAC (solvent A) and acetonitrile (solvent B), flow rate $0.5\ \text{mL/min}$, column temperature 25°C , sample injection volume $2\ \mu\text{L}$. The chromatograms were evaluated at $\lambda = 280\ \text{nm}$. The following gradient was used for separation: 9% acetonitrile (B) was flowed through the column isocratically with 91% solvent (A) for 0.8 min which was then increased to 55% acetonitrile (B) for 1.5 min, changed to 40% acetonitrile (B) for 2.3 min, to 30% acetonitrile (B) for 6.8 min, and finally 40% acetonitrile (B) for 8 min. The phenolic compounds were identified by comparing the chromatograms and retention times of the analytes with the reference standards.

Antioxidant activity determination: The total phenolic content was determined using the modified method of Folin-Ciocalteu (Wolfe, et al. 2003), and the content of flavonoids was determined using the method of Ordonez, et al. (2006). The testing of antioxidant activity using the Ferric reducing/Antioxidant power (FRAP) assay was carried out in accordance with Benzie, & Strain (1996); the 2,2-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS) assay using the modified method of Re, et al. (1999) and the 2,2 diphenyl-1-picryl-hydrazyl (DPPH) assay using the method of Brand-Williams, et al. (1995) with some modification. A $0.1\ \text{mM}$ solution of DPPH (1,1-diphenyl-2-picrylhydrazyl) in methanol was prepared. $1\ \text{mL}$ of aqueous honey solution was mixed with $1\ \text{mL}$ of DPPH solution. The mixture was left to stand for 30 min in the dark and absorbance was read spectrophotometrically at $517\ \text{nm}$. All the chemicals and reagents used were of analytical grade.

Sensory analysis of the initial and treated honey samples was conducted using a partially modified, quantitative descriptive evaluation of sensory properties, based on the method described in Grujić (2015), applicable to honey of varying quality levels.

RESULTS AND DISCUSSION

Table 1 presents the results of the physicochemical analysis of honeydew honey before and after freezing treatment. The water content in the control sample was 18.50%, while a slight increase was observed after treatment, reaching 18.74%. Subramanian, et al. (2007) reported a slight increase in water content in samples stored at low temperatures for an extended period, whereas Kędzierska-Matysek, et al. (2016) stated that freezing honey can lead to a reduction in water content, which contrasts with the values obtained in this study. Their analysis showed that honey stored at room temperature had a water content of 18.53%, while freezing at -20°C reduced it to 18.06%. The water activity (a_w) of the control sample was 0.597, which decreased to 0.587 after the treatment. Scripcă, & Amariei (2021) emphasized that water activity is directly related to the water content in the sample. A higher amount of free water facilitates the onset of fermentation and honey spoilage; therefore, reducing a_w through treatment is beneficial for extending honey's shelf life.

The pH value was 4.33, and after freezing, it decreased to 4.19. In the study by Kędzierska-Matysek, et al. (2016), a similar trend was observed, where the application of freezing led to a decrease in pH from 4.20 to 3.93. Chaikham, & Prangtip (2015) attribute the reduction in pH to the release of organic acids from pollen during honey processing. The acidity of the control sample was 45.17 mmol/kg, and after freezing, it increased to 45.75 mmol/kg. Similar results were reported by Kędzierska-Matysek, et al. (2016), who measured a total acid content of 18.71 mmol/kg in untreated honey, while freezing at -20°C led to an increase in acidity to 21.71 mmol/kg.

Based on the presented results, it can be observed that the sucrose content decreased from 2.01% to 1.96%. In contrast to the sugar content, the ash content increased significantly from 0.34 g/100 g to 0.62 g/100 g. These results correlate with the values of electrical conductivity, which measured 1.168 mS/cm in the control sample and increased to 1.235 mS/cm after treatment. Kędzierska-Matysek, et al. (2016) reported that the application of different storage temperatures does not significantly affect electrical conductivity. In their experiment, identical conductivity values were obtained before and after freezing, which was not confirmed in this study.

Table 1. Results of physico-chemical analysis of control and treated sample

Parameter	Control sample	Treated sample
Water content (%)	18.50 ± 0.19	18.74 ± 0.02
Water activity	0.597 ± 0.000	0.587 ± 0.001
pH value	4.33 ± 0.02	4.19 ± 0.00
Acidity (mmol/kg)	45.17 ± 0.29	45.75 ± 0.25
Sucrose content (%)	2.01 ± 0.00	1.96 ± 0.00
Ash content (g/100 g)	0.34 ± 0.01	0.62 ± 0.02
Electrical conductivity (mS/cm)	1.168 ± 0.00	1.235 ± 0.000
HMF content (mg/kg)	5.32 ± 0.25	24.78 ± 0.11
Diastase activity	47.67 ± 0.32	39.51 ± 1.63

Diastase activity and HMF content are indicators of honey freshness and exposure to heat (Fallico, et al., 2008; Hasan, 2013). The HMF content before treatment was 5.32 mg/kg, increasing to 24.78 mg/kg after freezing, which is in accordance with the current Regulation. Piekut, & Baranowska (2001) stated that minimal changes in HMF occur at freezing temperatures. Similarly, Kędzierska-Matysek, et al. (2016) emphasized that honey freshness is preserved under freezing conditions. Basmaci (2010) and Chua, et al. (2013) explained that HMF is formed as a result of the Maillard reaction, through the action of acids on hexoses, and that this process is accelerated at elevated temperatures. In addition to HMF content, honey freshness is also indicated by diastase activity, which decreased from 47.67 before treatment to 39.51 after freezing. Kędzierska-Matysek, et al. (2016) reported that freezing temperatures do not cause significant changes in diastase activity.

Table 2 presents the results of the antioxidant properties of honeydew honey before and after freezing treatment, as well as the results of HPLC analysis. The total phenolic content in the control sample was 1.485 mg GAE/g. After freezing, a slight decrease was observed, with the value reaching 1.415 mg GAE/g. The flavonoid content in the control sample was 0.846 mg GAE/g, and after treatment, a slight reduction was recorded, amounting to 0.714 mg GAE/g. The effect of low temperatures on phenolic compounds present in the product matrix has been examined in a limited number of studies.

Antioxidant activity was evaluated using FRAP, DPPH, and ABTS assays. The FRAP value of the control sample was 8.040 mmol Fe²⁺/g, and a slight increase was observed after the treatment, reaching 8.916 mmol Fe²⁺/g. A significant increase was observed in the DPPH value following freezing: the control sample showed 0.186 µg GAE/mg, while after treatment, the value rose to 0.368 µg GAE/mg. An improvement in antioxidant activity was also confirmed through the ABTS assay, expressed as IC₅₀ value, which represents the concentration of the sample required to inhibit 50% of free radicals. A greater ability to neutralize free radicals corresponds to lower ABTS values, i.e., lower IC₅₀ values indicate higher antioxidant activity (Pontis, et al., 2014). In the control sample, the IC₅₀ value was 0.0044 mg/g, which decreased to 0.0038 mg/g after freezing.

Neri, et al. (2020) reported that freezing has a negative impact on the antioxidant properties of fruit purees and juices, while Çubukçu, et al. (2019) analyzed the antioxidant activity of various types of vegetables before and after freezing and found that antioxidant activity increased in some types and decreased in others.

Table 2. Results of antioxidant properties analysis and HPLC analysis

Parameter	Control sample	Treated sample
Total phenolic content (mg GAE/g)	1.485 ± 0.0238	1.415 ± 0.002
Total flavonoid content (mg GAE/g)	0.848 ± 0.005	0.714 ± 0.003
FRAP (mmol Fe ²⁺ /g)	8.040 ± 0.081	8.916 ± 0.162
DPPH (µg GAE/mg)	0.186 ± 0.001	0.368 ± 0.002
ABTS (g/mg)	0.0044 ± 0.0006	0.0038 ± 0.0003
Catechin (mg/100 g)	0.804	1.636
Malvidin (mg/100 g)	0.264	0.499
Galic acid (mg/100 g)	0.014	0.077

Table 2 also includes the results of the HPLC analysis. Numerous studies have shown that honey contains a wide variety of phenolic and flavonoid compounds. The composition of these compounds depends on the botanical origin, as well as ecological, seasonal, and processing conditions (Lachman, et al., 2010; Oliveira, et al., 2017). HPLC-DAD analysis of the examined samples confirmed the presence of catechin, malvidin, and gallic acid, with catechin being the most abundant and gallic acid the least abundant compound.

Following the freezing treatment, an increase in the content of all three components was observed. The catechin content increased from 0.804 mg/100 g to 1.636 mg/100 g. The malvidin content rose from 0.264 mg/100 g to 0.499 mg/100 g, while gallic acid content increased from 0.014 mg/100 g to 0.077 mg/100 g. Based on these results, it can be concluded that most analyses indicate an improvement in the antioxidant properties of this honeydew honey as a result of the freezing treatment.

Table 3 presents the results of the sensory analysis of the treated honeydew honey and the differences in individual sensory attributes between the control and treated samples. Honeydew honey is characterized as a dark-colored type of honey (Ngoi, 2016). The honeydew honey used in this study had a dark, homogeneous color. The application of freezing treatment did not significantly affect the color, indicating good preservation of product quality under low-temperature conditions.

The consistency of the control sample was thick and viscous, with fine granules perceptible under the tongue. After treatment, small lumps formed in the structure of the honeydew honey.

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This consistency led to uneven dripping from a spoon, as the treated sample was significantly thicker than the control. The aroma of the control sample was described as clean, intense, and highly pleasant. Freezing largely preserved the aroma. The taste of the control sample was described as pleasant and clean, specific to honeydew honey, with no presence of off-flavors or odors. After treatment, the taste and aroma did not change significantly.

The overall impression indicates that freezing may represent an alternative method for preserving the quality and sensory characteristics of honeydew honey.

Table 3. Sensory analysis results of honeydew honey, including the evaluation of differences between the treated and control samples.

Parameter		Control sample	Treated sample
Color	evaluation	5 ± 0.00	4.10 ± 0.22
	difference	-	2.00 ± 0.71
Consistency and texture	evaluation	5 ± 0.00	4.60 ± 0.22
	difference	-	0.80 ± 0.45
Aroma	evaluation	5 ± 0.00	4.40 ± 0.42
	difference	-	1.20 ± 1.10
Taste and odor	evaluation	5 ± 0.00	4.50 ± 0.35
	difference	-	1.20 ± 1.10
Overall impression	evaluation	5 ± 0.00	4.40 ± 0.22
	difference	-	1.20 ± 0.45

CONCLUSIONS

The application of low temperatures represents a suitable alternative method for preserving the quality of honeydew honey, particularly in terms of its sensory and antioxidant properties. Moreover, low-temperature treatment did not negatively affect the majority of physicochemical parameters, with the exception of hydroxymethylfurfural (HMF) content and diastase activity, where an increase in these values was observed. These parameters are commonly associated with prolonged storage or thermal treatment of honeydew honey.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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CIRCULAR ECONOMY: IMMOBILIZATION OF *LACTOBACILLUS ACIDOPHILUS* ON FLAXSEED CAKE

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ABSTRACT

Lactobacillus acidophilus has been increasingly studied as a probiotic for allergy treatment. For probiotics to deliver their beneficial effects, they need to be present in adequate numbers, which is often achieved by immobilizing them within protective matrices. A flaxseed cake is rich in fibers, proteins, and bioactive components, which makes it a potential good carrier for probiotics.

Flaxseed cake, obtained from the cold-pressed oils industry, was ground, sieved to a diameter of less than 600µm, sterilized, and diluted in distilled water at 10 % (w/v). After *L. acidophilus* inoculation, one sample was fermented, incubated at 4 °C for 1 h, frozen, and freeze-dried, while the other was subjected to every step but fermentation. The lyophilized probiotic powder was examined for probiotic viability and antioxidant capacity.

The probiotic culture showed a high survival rate in both samples. The fermentation decreased probiotic viability during the lyophilization procedure by 13 % but significantly increased the antioxidant activity of probiotic powder. The results indicate that flaxseed cake is a good probiotic carrier.

Keywords: probiotics, freeze-dry, immobilization, flaxseed residue, antioxidant

INTRODUCTION

The circular economy promotes sustainable practices by reusing agricultural by-products in value-added applications. One such by-product, flaxseed cake, the material remaining after cold pressing flaxseed (*Linum usitatissimum* L.) oil, is increasingly recognized for its high protein and fiber content, along with bioactive compounds such as lignans and polyphenols, which make it suitable as a functional food ingredient and a carrier for probiotic bacteria (Gutiérrez, et al., 2010). The integration of such by-products supports not only nutritional innovations but also environmental sustainability through waste valorization.

The global demand for cold-pressed flaxseed oil has grown significantly in recent years, driven by its health-promoting properties, particularly its high omega-3 fatty acid content, and consumer interest in plant-based and clean-label products. This market expansion has increased the availability of flaxseed cake, enhancing its potential for further functional applications, including in non-dairy probiotic formulations (Łopusiewicz, et al., 2021).

Immobilization is a well-established technique increasingly utilized in the food industry, particularly for enhancing the stability and functionality of probiotics. This method offers several advantages, primarily by protecting probiotic cells within a carrier matrix from external stressors. As a result, immobilized probiotics exhibit improved survival during processing, storage, and under adverse environmental conditions (Krunić, et al., 2016).

Notably, immobilization enhances the viability of probiotic bacteria by protecting them from harsh conditions, such as low pH, digestive enzymes, and bile salts, in the human gastrointestinal tract (Krunić, et al., 2016; Krunić, et al., 2019). A fundamental criterion for successful immobilization is maintaining the viability of bacterial cells, which has guided the selection of appropriate immobilization techniques.

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Among these, emulsification and extrusion are two commonly employed encapsulation methods that effectively preserve probiotic viability. Emulsification offers the flexibility of producing microcapsules across a broad particle size range (0.2–5000 µm), whereas extrusion yields more uniform beads within a narrower size distribution (Burgain, et al., 2011; Krunic, et al., 2019). However, the extrusion method is limited by its low throughput and difficulty in scaling up due to the slow formation rate of encapsulated carriers.

Spray drying is one of the most widely adopted microencapsulation techniques, particularly for industrial applications, owing to its rapid processing time, cost-efficiency, and ability to produce stable, high-quality end products. Nonetheless, the exposure of probiotic cells to high temperatures and dry air during spray drying can compromise cell viability. Therefore, careful optimization of processing parameters is essential to mitigate thermal stress and ensure maximal survival (Barbosa, et al., 2015).

Among probiotic delivery strategies, lyophilization (freeze-drying) stands out as one of the most effective methods for immobilizing probiotic microorganisms. Compared to other techniques such as gel entrapment or spray-drying, lyophilization provides superior bacterial viability during storage and gastrointestinal transit, while maintaining functionality and scalability for industrial use (Łopusiewicz, et al., 2021).

The probiotic *Lactobacillus acidophilus* is widely recognized for its health benefits. It supports gut microbiota balance, improves immune response, and has been linked to alleviation of lactose intolerance and the inhibition of pathogens. It is commonly used in fermented dairy products, probiotic supplements, and plant-based functional foods. Its ability to adhere to intestinal cells, produce antimicrobial substances, and modulate host responses makes it a model organism for probiotic studies (Łopusiewicz, et al., 2021).

Immobilizing probiotics serves several important purposes: it enhances survivability during processing and storage, protects against acidic and enzymatic degradation in the gastrointestinal tract, and enables controlled release of the bacteria at the site of action. These advantages are critical for ensuring probiotic efficacy in real-world applications (Łopusiewicz, et al., 2021).

Historically, both flaxseed and fermented probiotics have been valued in traditional medicine and diets. Flaxseed has been cultivated for millennia, not only for oil production but also for its digestive and anti-inflammatory properties, while probiotic use dates back to ancient fermented foods like yogurt. The modern scientific validation of these traditional practices now supports their integration into functional and sustainable food systems.

This study explores the immobilization of *Lactobacillus acidophilus* on flaxseed cake using freeze-drying, as a novel application aligned with circular economy principles, aiming to valorize agricultural waste while enhancing probiotic delivery

MATERIALS AND METHODS

Materials

In this work was used flaxseed cake obtained from Linum d.o.o., Serbia, and *Lactobacillus acidophilus*, Now foods, USA. DPPH (2,2-diphenyl-1-picrylhydrazyl), ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)), and other analytical grade reagents were purchased from Sigma-Aldrich Chemie GmbH, USA.

Flaxseed cake pre-treatment

Flaxseed cake, obtained from the cold-pressed oils industry, was used. The composition of the raw material was determined before immobilization. Flaxseed cake was ground in a ball mill and sieved through a sieve with a pore size of 0.6 mm. The flaxseed powder obtained in this way was sterilized in an autoclave at 120 °C, with a pressure of 1.5 bar for 30 minutes. After sterilization, the flaxseed powder was diluted in distilled water to a 10 % (w/v) concentration.

Culture activation and lyophilization

L. acidophilus from the frozen stock was incubated under anaerobic conditions in De Man, Rogosa and Sharpe (MRS) broth (Torlak, Serbia) at 37 °C for 18 h two times consecutively and

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then washed in 10 mL of NS 3 times. The obtained culture was centrifuged at 4000 rpm for 5 min, and bacterial pellets were further re-suspended in 1 mL of NS and then added to two Erlenmeyer flasks with 50 mL of 10 % flaxseed powder dilution. One sample was poured onto a plastic plate for lyophilisation, frozen at -80 °C, and then freeze-dried for 24 h. The second sample was incubated at 37 °C for 3.5 h, then poured onto a plastic plate for lyophilisation, frozen at -80 °C, and freeze-dried for 24 h.

Viable cell number determination

Viable cell numbers were determined before and after immobilization by the pure plate method. The cell number was expressed as CFU/g and calculated percentage of viability after lyophilisation, which is the immobilization efficiency (IE).

$$IE \% = \frac{Ni}{N} \times 100$$

Ni is the total number of bacteria immobilized on the carrier (CFU/g) calculated relative to the weight of the carrier; N is the total number of bacteria in the suspension before the immobilization procedure (CFU/g).

The obtained values for the number of cells are recalculated in relation to the logarithmic value of the obtained number of cells.

Antioxidant capacity

Determination of inhibition of DPPH free radicals

The flaxseed cake powder before and after probiotic immobilization were taken in 1 % dilution and mixed with 0.1 mM–thanollic DPPH free radical, in ratio 1 : 18. Mixtures were homogenized and left in the dark for 30 min. The absorbance was measured at 517 nm using a UV-visible spectrophotometer (Ultrospec 3300 pro, Amerischam Bioscienc). For control, ethanol was used instead of the sample. The antioxidant activity was expressed as a percentage of DPPH activity calculated as:

$$DPPH \text{ capacity } (\%) = \frac{\text{Absorbance of blank} - \text{Absorbance of sample}}{\text{Absorbance of blank}} \times 100$$

ABTS free radical scavenging activity assay

The ability of samples to scavenge ABTS radical was tested before and after the immobilization process using method described by Re, et al., (1999). ABTS radical cation was produced in the reaction between ABTS (7 mM) and potassium persulfate (2.45 mM final concentration). The reaction mixture was kept in the dark at room temperature for 16 h before use. Further, ABTS solution was diluted with 5 mM phosphate-buffered saline (pH 7.4) until the absorbance of 0.700 ($\pm$ 0.030) was reached. Diluted ABTS solution was mixed with samples (prepared in different dilutions) in a ratio 100 : 1; absorbance was measured at 734 nm after 5 min. The antioxidant activity was expressed as a percentage of free radicals inhibition calculated as:

$$ABTS \text{ capacity } (\%) = \frac{\text{Absorbance of blank} - \text{Absorbance of sample}}{\text{Absorbance of blank}} \times 100$$

Statistical analysis

All experiments were performed in triplicate and the results are presented as means with standard deviations. The Tukey test was used to determine significant differences between samples

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($p < 0.05$). Data analysis was conducted using Microsoft Excel (Microsoft Office 2013 Edition, USA) and OriginPro 8 (Origin Lab Co., Northampton, USA).

RESULTS AND DISCUSSION

This study investigates the potential use of flaxseed cake, a by-product generated in large quantities during the production of cold-pressed flaxseed oil, as a carrier for probiotics. The experimental workflow is illustrated in Figure 1.

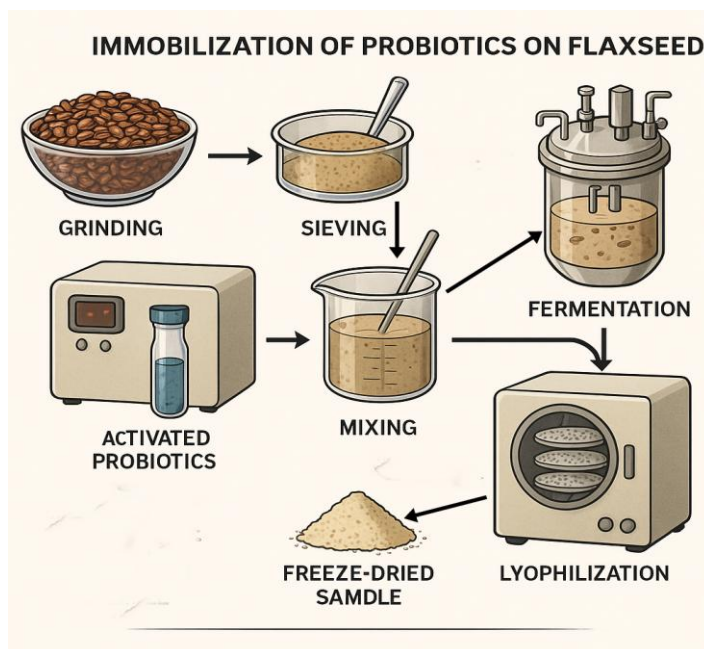


Figure 1. Experimental scheme

The flaxseed cake, which is produced in approximately double the quantity of the final product (flaxseed oil), was a huge pollutant because it has not found a way to an appropriate number of consumers. Using it as raw material is a circular economy. Flaxseed cake was first ground and then sieved to obtain powder particles smaller than 600 μm . These particles are sufficiently small to be incorporated into food products without significantly altering their rheological properties, and large enough to be carriers for bacteria.

Prior to further experimentation, the composition of the flaxseed powder was determined and is presented in Table 1. The observed ratio of fiber to protein indicates a promising potential as a probiotic carrier. Dietary fibers not only serve as a nutrient source for probiotics but also provide protection against environmental stress by forming a network or gel-like structure in aqueous solutions. In addition to their protective capacity, proteins possess inherent bioactive potential. Carbohydrates are also food for used probiotic bacteria.

Table 1. Flaxseed cake composition

	Protein, %	Oil, %	Fiber, %	Carbohydrate, %	Moister, %
Flaxseed cake	37.1 ± 2.5	20.7 ± 1.2	28.0 ± 3.5	7.1 ± 0.8	8.1 ± 0.9

Figure 2. shows viable cell numbers before and after immobilization for non-fermented and fermented flaxseed probiotic powder. The number of viable probiotic bacteria was significantly higher before the lyophilization process, which is in accordance with previously published data

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(Krunic, & Osmokrovic, 2025). During lyophilization, a substantial loss of viable cells occurs due to the formation of damaging ice crystals during the freezing phase. The use of various cryoprotectants can significantly enhance probiotic survival. In our study, a survival rate of 80 % was achieved, which is notably higher compared to the survival of the culture in physiological saline (67 %, data not shown). These findings suggest that the flaxseed cake exhibits a protective effect during the lyophilization process. Soltani, Sadeghi, & Shirvani (2025) show improved *L. acidophilus* viability and metabolic activity by the addition of flaxseed gum.

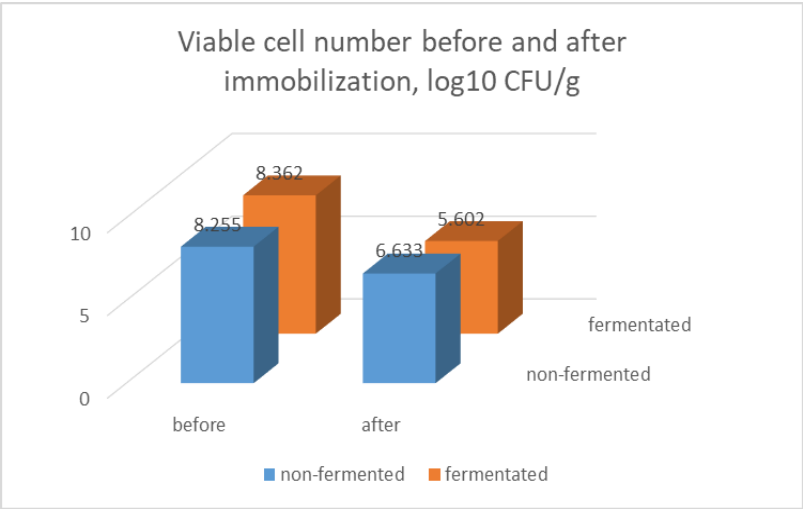


Figure 2. Viable cell numbers before and after 24h of lyophilization for non-fermented and fermented flaxseed probiotic powder

Fermentation of flaxseed was introduced with the aim of modifying the carrier structure through microbial hydrolysis of proteins and fibers, thereby enhancing probiotic binding. Fermentation by *L. acidophilus* altered the flaxseed gum to be more porous and improved its functional properties, such as swelling, water-holding, and oil-holding capacities (Wang, et al., 2024). However, the results demonstrated a 13% lower probiotic survival rate following this treatment compared to the non-fermented sample (Table 2). This can be explained by the additional activation of probiotics during fermentation, which brings them into a more sensitive phase. Although fermentation did not show a positive influence on the survival of probiotics during lyophilization, Theegala, et al. (2021) demonstrated that flaxseed provides a high protective capacity toward probiotics under simulated gastrointestinal conditions.

Table 2 Immobilization efficiency of fermented and non-fermented flaxseed powder

	Non-fermented	Fermented
Immobilization efficiency (IE), %	80.1 ± 2.2	67.2 ± 2.1

Based on these findings, it can be concluded that non-fermented flaxseed serves as a more effective cryoprotectant and carrier for the applied probiotic strain during the lyophilization process. Microbial hydrolysis, i.e., fermentation of flaxseed, does not increase probiotic viability and immobilization efficiency but may lead to an increase in the bioactivity of the raw material. This is primarily a result of the microbial hydrolysis of flaxseed proteins, as well as the formation of new bioactive peptides and molecules by the probiotic culture. As shown in Figure 3, the antioxidant capacity of the fermented flaxseed probiotic powder was significantly higher, in a statistically significant manner, compared to the non-fermented sample. This effect is likely due to the biotransformation or release of phenolic compounds and other bioactive substances during fermentation. Research supports that *L. acidophilus* and other lactic acid bacteria improve the

antioxidant potential of plant-based substrates, including flaxseed, by modifying polysaccharide structure, increasing polyphenol content, and producing metabolites with antioxidant activity. Results from this paper are in accordance with the literature, which shows that fermentation with *L. acidophilus* leads to increased antioxidant activity in flaxseed (Wang et al., 2024). In soy and almond milk systems, *L. acidophilus* significantly improved antioxidant capacity and polyphenol content during fermentation (Zahrani, & Shori, 2023). Also, *L. acidophilus* enhanced the antioxidant activity of fermented apple pulp by biotransforming polyphenols into more bioavailable compounds (Ran, et al., 2023). Waszkowiak, et al. (2025) show that fermenting bacteria caused changes in important functional and technological properties of flaxseed cake, such as the increase in the antiradical activity and total phenolic content, and the decrease in the water holding capacity and viscosity. These changes can be particularly beneficial for food applications. Since *L. acidophilus* is not considered a metabolically highly active bacterium and fermentation takes only 3.5 h, the observed antioxidant capacity of probiotic powder is more likely a result of flaxseed protein hydrolysis rather than the production of various antioxidant-active compounds during fermentation.

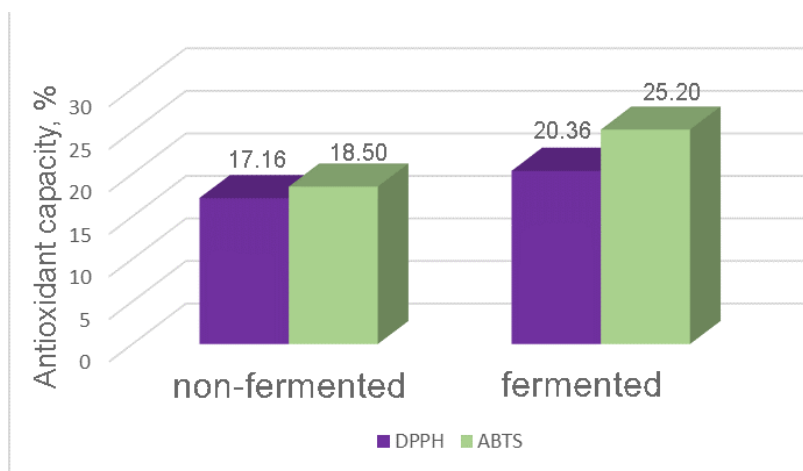


Figure 3. Antioxidant capacity of flaxseed probiotic powder after immobilization. One sample was fermented for 3.5 h before the immobilization process.

CONCLUSION

The high fiber content of about 28 % and protein of about 37 % in flaxseed cake makes it a material with good potential for use as a probiotic carrier. The probiotic culture showed a high survival rate in both samples. The non-fermented sample showed a survival rate of *L. acidophilus* of 80 %, while fermentation decreased probiotic viability during the lyophilization procedure by 13 %. These results show that flaxseed cake powder is a good material for immobilizing probiotics, providing them with a high percentage of viability. Although fermentation is often a good method for improving the properties of materials and products. In this research, fermentation of flaxseed significantly increased the antioxidant activity of probiotic powder. The reason for the reduced number of viable cells in the fermented compared to the non-fermented sample may be the adaptation of the culture to the fermentation temperature, as well as the introduction of the culture into the accelerated growth phase when it is highly sensitive to external factors. This can be remedied by extending the time of storing the samples in the refrigerator before freezing and lyophilization.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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IMPACT OF TREHALOSE-BASED CRYOPROTECTANT ON IMMOBILIZATION AND RELEASE OF *LACTOBACILLUS PLANTARUM* OBTAINED FOR WOUND DRESSING

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ABSTRACT

Lactobacillus plantarum has been increasingly studied and applied in the context of wound healing and wound dressings, thanks to its antimicrobial, anti-inflammatory, and biofilm-disrupting properties. In some approaches, lyophilized (freeze-dried) *L. plantarum* is applied as a powder or mixed with a carrier to facilitate topical delivery.

L. plantarum was diluted in 10 % trehalose and a mixture of 5 % trehalose and skim milk. The mixtures were aseptically added on top of activated carbon (AC) pads, frozen at -80°C , and freeze-dried for 5 h. Immobilized probiotics on AC pads were incubated in normal saline at 37°C for 24 h. The immobilization efficiency after lyophilization and the release of probiotics from the pad after 10 minutes, 3 h, and 24 h were determined.

The combination of trehalose and skim milk showed significantly better results, maintaining almost 80 % viability after 24 h. Trehalose alone preserved almost half as many probiotics compared to trehalose with milk. Since the controlled release of probiotics is essential for their antimicrobial effectiveness in wound dressings, it can be concluded that the AC pad containing probiotics protected with both trehalose and skim milk is a more effective option than the probiotics protected with trehalose alone.

Keywords: *Lactobacillus plantarum*, freeze-dry, immobilization, AC pad, milk.

INTRODUCTION

Lactobacillus plantarum has been increasingly studied and applied in the context of wound healing and wound dressings, thanks to its antimicrobial, anti-inflammatory, and biofilm disruption properties. *L. plantarum* produces organic acids (like lactic acid), hydrogen peroxide, and bacteriocins that inhibit common wound pathogens such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Escherichia coli*. In addition, it helps reduce inflammation by modulating cytokine production, which can accelerate the healing process.

One of the key challenges in developing efficient probiotic systems for various applications, such as wound dressing, is ensuring effective cell preservation (Krunic, et al., 2016; Krunic, et al., 2019). The primary goal of preserving cells is to maintain their viability without altering their biochemical, morphological, physiological, or genetic characteristics (Malik, 1988). Although several effective cell preservation strategies exist, lyophilization (or freeze-drying) is widely regarded as the gold standard in the biopharmaceutical industry, particularly when working with sensitive microbial cells. During freeze-drying, bacterial cells are subjected to low temperatures and the removal of water. The freezing phase can cause cellular damage due to ice crystal formation and osmotic stress.

To minimize such damage, various protectants are often added to the drying medium. These substances help stabilize the cells in the absence of water and form a supportive matrix that maintains the structure of the sample throughout the process. In doing so, protectants help preserve

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cell viability, ensure stability, and facilitate easy rehydration. A wide range of materials have been tested for their protective capabilities, including skim milk, polyols, polysaccharides, disaccharides, amino acids, proteins, minerals, organic acid salts, and vitamins (Champagne, et al., 1991; Hubalek, 2003). However, even with effective protectants, sensitive microorganisms like lactic acid bacteria (LAB) may still experience a loss of viability and stability (Krunić, & Osmokrović, 2025).

To address these limitations, researchers have explored new methodologies. One promising and straightforward approach is the immobilization of microorganisms on various carriers using physical or chemical methods (Bouabidi, et al., 2019).

Immobilization is a well-established technique widely used across various industries. When applied to probiotics, immobilization offers numerous advantages. By embedding probiotics in a carrier, they are protected from external environmental stressors, enhancing their ability to survive manufacturing processes, storage conditions, and extended shelf life. This technique significantly improves the viability of probiotic bacteria under adverse conditions during both processing and storage (Krunić, et al., 2016). Moreover, immobilized probiotics are better equipped to withstand the harsh environment of the human gastrointestinal tract, including low pH, digestive enzymes, and bile salts (Krunić, et al., 2016; Krunić, et al., 2019). A fundamental requirement of any immobilization technology is maintaining the viability of bacterial cells, which plays a key role in selecting the appropriate method.

Another crucial factor for using immobilized material is the controlled release of it into the surrounding environment. Depending on the application, it may be necessary to release a large number of cells rapidly, or in some cases, a sustained and gradual release is more desirable. These release dynamics must be carefully considered when choosing both the immobilization technique and the carrier material (Krunić, et al., 2016).

In this study, we investigated the impact of trehalose alone and in combination with milk on the viability of probiotic cells during the immobilization process, as well as their effect on the subsequent release of cells from the carrier. Activated carbon (AC) pads were used as the immobilization carrier, while freeze-drying was an immobilization technique.

MATERIALS AND METHODS

Materials

AC pads were prepared in a circular shape by punching from activated carbon fabric (ACF, ConvaTec, USA). Other materials were trehalose dehydrate (Carl Roth, Germany), skim milk (Imlek, Serbia), NaCl (Sigma, USA), De Man, Rogosa and Sharpe (MRS) broth, and Agar (Torlak, Serbia). Other analytical grade reagents were purchased from Sigma-Aldrich Chemie GmbH, USA. *Lactobacillus plantarum* (Lp299v) was obtained from Abela Pharm, Croatia.

Preparation of probiotic for freeze-drying

L. plantarum from the frozen stock was subsequently incubated under anaerobic conditions in MRS broth at 37 °C for 18 hours, twice in succession. After incubation, the bacterial culture was washed three times with 10 mL of NS (normal saline solution, 0.9 % w/v NaCl). The resulting culture was then centrifuged at 4000 rpm for 5 minutes, and the bacterial pellets were resuspended in 1 mL of various freeze-drying media. Two protective media were used: 10% trehalose and a mixture of 5 % trehalose with 5 % skim milk. All freeze-drying solutions were sterilized using a 0.2 µm filter prior to mixing with the bacterial cells. Control was a culture without a cryoprotectant.

Freeze-drying immobilization of *L. plantarum* on AC pads

AC pads were put in a glass Petri dish, sterilized with hot air at 160°C for 2h, and then used for bacterial cell immobilization. Concretely, 100 µL of freeze-drying media mixed with cells was aseptically added on top of each pad and left to settle for 15 min at room temperature. The samples were then placed in plastic Petri dishes, frozen at -80 °C, and subsequently freeze-dried for 5 hours at -40 °C under a pressure of 0.12 mbar using a Beta 2-8 LD plus freeze dryer (Christ, Germany).

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After freeze-drying, AC pads with immobilized cells were gold-coated and examined using a MIRA 3 XMU Field Emission Scanning Electron Microscope (Tescan USA Inc., Cranberry Township, PA).

Probiotic viability and immobilization efficiency (IE) during freeze-drying

Viable cell numbers were determined before and after immobilization by the pure plate method. The cell number was expressed as CFU/pad and calculated percentage of viability after freeze-drying, which is the immobilization efficiency (IE).

$$IE \% = \frac{N_i}{N} \times 100$$

N_i is the total number of bacteria immobilized on the carrier (CFU/g) calculated relative to the weight of the carrier; N is the total number of bacteria in the suspension before the immobilization procedure (CFU/g).

The obtained values for the number of cells are recalculated in relation to the logarithmic value of the obtained number of cells.

Probiotic viability and release capacity of AC pads after freeze-drying process during 24 h

The pads containing immobilized probiotics were incubated in 2 mL of normal saline at 37 °C for 10 minutes, 3, and 24 h. At each time point, the release of viable cells into the solution was assessed. The number of live cells was determined using the pour plate method and expressed as $\log_{10}$ CFU/pad

Statistical analysis

Experiments were performed in triplicate. All values are expressed as mean $\pm$ standard deviation. Mean values were analyzed using one-way ANOVA. The Tukey post hoc test was performed for means comparison (Origin Pro 8 (1991-2007) computer package, Origin Lab Co., Northampton, USA). Data analysis was conducted using Microsoft Excel (Microsoft Office 2013 Edition, USA) and OriginPro 8 (Origin Lab Co., Northampton, USA). Data was considered significantly different when $P < 0.05$.

RESULTS AND DISCUSSION

Figure 1 illustrates the experimental process employed in this study to create an innovative probiotic-activated carbon-based wound pad.

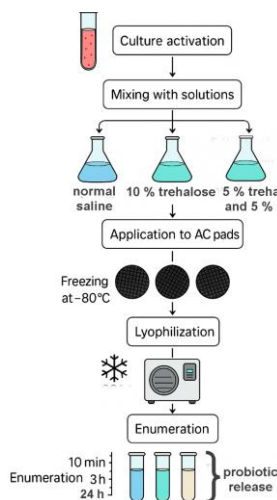


Figure 1. Scheme of experimental process.

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AC pads fabricated via a punching process had an average diameter of approximately 12 mm (Fig. 2) and a mean weight of 0.017 ± 0.001 g. Bacterial immobilization was performed by directly applying 100 μ L of a bacterial cell suspension, with or without protective agents, onto each AC pad. Following freeze-drying, the morphology of the carrier and the immobilized cells was examined using optical microscopy and field-emission scanning electron microscopy (FE-SEM) (Figure 2).



Figure 2. Optical and field emission scanning electron microscopy.

In this study, ACF was selected as a carrier for the freeze-drying of immobilized probiotics due to its excellent thermal conductivity. Carbon-based materials are known to facilitate efficient heat transfer throughout the sample matrix, thereby minimizing the risk of cellular damage during the lyophilization process (Malik, 1990).

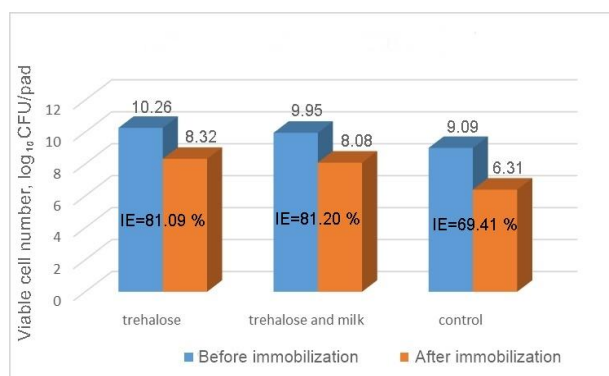


Figure 3. Probiotic viability before and after 5 h of the freeze-dry process and immobilization efficiency (IE) for samples with 10 % trehalose, with 5 % trehalose and 5 % milk, and control (without cryoprotectant).

As shown in Figure 3, trehalose and the combination of trehalose and milk exhibit very similar protective capacities, which significantly increased the number of viable probiotics during the immobilization process compared to the control sample without cryoprotectants. This is consistent with the literature, which has demonstrated that trehalose, as well as sucrose, provides a high degree of protection against bacterial freezing, similar to milk (Krunic, & Osmokrovic, 2025; Oluwatosin, et al., 2022). Also, Jia-Peng, et al. (2008) showed that a mixture of 3.34 % skim milk and 1.85 % trehalose resulted in a 96.8% survival rate of *L. plantarum* after lyophilization based on response surface methodology (RSM). Another RSM-based study found that 24.06 % skim milk and 5.63 % trehalose significantly improved *L. plantarum* viability, and highlighted the synergistic effect between milk and trehalose (Gisela, et al., 2014). Trehalose is a well-known and widely utilized protectant across the food, medical, pharmaceutical, and cosmetic industries. Although recent advancements in enzymatic production technologies have substantially reduced the cost of trehalose, it remains more expensive than commonly used sugars such as glucose and sucrose. However, a disadvantage associated with sucrose and other sugars is the increased stiffness of the sample following the application of these cryoprotectants. In such cases, milk is preferred, as is the sample containing both milk and trehalose in our study, as it results in a considerably less stiff structure, as well as being less expensive. These cryoprotectants not only influence the viability and survival of the probiotic culture during the immobilization process, but also affect the release of probiotics from the carrier. As shown in Figure 4, trehalose and the combination of trehalose

and milk result in a high release rate within the first 10 minutes as well as within the first 3 hours in normal saline solution. The control sample exhibits a statistically significantly lower number of released viable bacteria in the first 10 min, which is a consequence of the considerably lower survival rate during the immobilization process compared to the other two samples. After 3 hours, the number of viable probiotics in the control decreases by 17 %, while in the samples with cryoprotectants, the reduction is 3 % for trehalose and 1 % for the trehalose-milk combination. The greatest difference among the samples is observed after 24 hours: the number of viable probiotics in the control sample drops by 100 %, whereas the decrease is 44 % in the trehalose sample and 3.7 % in the sample with the trehalose-milk combination.

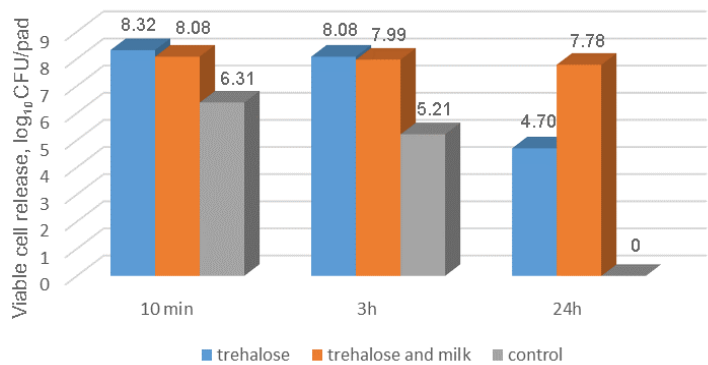


Figure 4. Viable cell number of release *L. plantarum* from AC pads in NS after 24h.

The release of bacteria from the carrier matrix is a critical factor when applying immobilized probiotics in wound dressing applications. For probiotics to exert their beneficial effects—such as modulating the local microbiota, producing antimicrobial compounds, reducing inflammation, and promoting tissue regeneration—they must be able to detach from the carrier and colonize the wound environment. An efficient and controlled release ensures that a sufficient number of viable cells reach the wound site and remain metabolically active, which is essential for achieving the desired therapeutic outcomes (Osmokrovic, et al., 2025). Furthermore, sustained release can prolong the probiotic action, enhancing the overall efficacy of the wound treatment.

Based on the obtained results, it can be concluded that the combination of trehalose and milk significantly enhances the survival of the probiotic culture during the immobilization process compared to the control sample, as well as during the release process when compared to both the control and the trehalose-only sample. Overall, these findings suggest that the combination of milk and trehalose is the most effective choice for the immobilization of *L. plantarum* by lyophilization onto an AC pad intended for wound dressing applications.

CONCLUSIONS

The results of this study demonstrate that the use of cryoprotectants, particularly the combination of trehalose and milk, plays a critical role in enhancing the viability of *L. plantarum* during the immobilization process onto AC pads and in promoting its subsequent release in a simulated wound environment. Compared to the control sample and the sample containing trehalose alone, the trehalose-milk combination significantly improved bacterial survival rates post-lyophilization and ensured a more efficient and sustained release of viable probiotic cells over 24 hours. These findings are consistent with previous reports highlighting the protective effects of trehalose and milk during freeze-drying. Moreover, the ability of probiotics to be released from the carrier is essential for their functional performance in wound care, including microbiota modulation, antimicrobial activity, and tissue regeneration. Therefore, the combination of trehalose and milk appears to be the most effective and practical choice for the immobilization of *L.*

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plantarum on AC wound dressing pads, offering both enhanced protection during processing and optimal functionality upon application.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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SODIUM CHLORIDE SOLUTION TEST OF Ti₆Al₄V IMPLANT SPECIMENS MANUFACTURED BY ADDITIVE TECHNOLOGY

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ABSTRACT

Additive technology is a valuable process for medical implant manufacturing. The most common metallic material in this area is the Ti₆Al₄V alloy. The research aimed to learn the behaviour of the implant material in saltwater environments. During the sodium chloride test, the weight loss of the test sample and the solute ion concentration are evaluated. The corrosion resistance tests were performed with a 3% concentration of NaCl solution at 36°C, with a duration of 4, 8, 12, and 16 days. The weight loss quality is determined by the test sample weight measured before and after the tests. The NaCl solution was also tested to characterise the most relevant quality element, which was retrieved from the implant material during the test. The solute metal ion concentration in the NaCl solution is determined by an inductively coupled plasma–optical emission spectroscope (ICP). Based on the experimental results, it can be declared that the weight loss increased as a function of time, and the measurable element was the aluminium in the NaCl solution. The chemical component of aluminium can cause many diseases and health problems. Aluminium can have various harmful effects on the human body, including neurological problems, lung disease, anaemia, bone and muscle damage, and skin inflammation. Some studies have also linked it to Alzheimer's disease and breast cancer. Untreated 3D-printed Ti₆Al₄V alloys show significant aluminium leaching, highlighting the need for surface modification before clinical application..

Keywords: corrosion, additive manufacturing, Ti₆Al₄V, ICP test, implant.

INTRODUCTION

Titanium alloys, in particular Ti₆Al₄V, are important alloys for dental and orthopaedic implants due to their excellent mechanical and biological properties (Haydar, et al., 2021; Wang, et al., 2020). In recent years, there has been increasing interest in the use of 3D powder bed metal deposition technology (selective laser melting, SLM) for the fabrication of Ti₆Al₄V medical implants instead of powder metallurgy, forging and casting processes. The 3D printing process increased the use of titanium alloy applications in several areas, such as aerospace and medical applications. The lightweight metal alloys have excellent mechanical properties such as strength and ductility.

Titanium and its alloys exhibit biocompatibility, which is a key factor in their importance in medical technology, such as implants (Naghavi, et al., 2022). It is well understood and tested that different chemical elements in the functioning of the human body can be beneficial, harmful, or toxic to healthy functioning. In the case of the Ti₆Al₄V alloy, aluminium is the most dangerous element and is responsible for the health disease (Jomova, et al., 2022).

Kovács, T. A. et al. (2025). Sodium chloride solution test of Ti6Al4V implant specimens manufactured by additive technology. *STED Conference 14(2)*, 273-278.

Titanium alloy, Ti6Al4V, is widely used for dental implants due to its lightweight, high strength, and biocompatibility (Nicholson, 2020). However, there is concern that over time, the implant will corrode and may release aluminium and vanadium ions into the body (Noumbissi, et al., 2019; Tyczyńska, et al., 2024; Qureshi, 2021).

Few studies show that the release rate of the ions depends on several factors, such as the acidity level of the mouth environment and the mechanical pressure applied to the implants (Delgado-Ruiz, & Romanos, 2018; Saha, & Roy, 2022). Arregui et al. reported that the number of aluminium ions released may be small, but long-term exposure still raises questions about the safety of the implants, as elevated levels of aluminium can be toxic and may lead to renal failure (Arregui, et al., 2021). It is noted that the acceptable range of aluminium in the blood is typically less than 16 µg/L (Sjögren, et al., 2015). Arregui et al. also concluded that while the number of aluminium ions released increased over time, the amount of vanadium ions released was negligible in the case of the Ti6Al4V alloy experimented with (Arregui, et al., 2021; Laupheimer, et al., 2024).

The researchers tested the Ti6Al4V alloy corrosion resistance by several methods to determine its corrosion behaviour (Sharp, et al., 2022; Chen, et al., 2022). In the case of this alloy, a wear damage phenomenon was detected. The wear process causes weight loss (Nsiah-Baafi, et al., 2022). The porosity level of the 3D printed materials can be the reason for the weight loss. The electrolyte during the corrosion tests can penetrate the pores, and in this way, the contact surface is much greater than in the case of a metal without porosity (Morris, et al., 2021). The surface roughness and the porosity level can increase the osseointegration of the implant (Kia, et al., 2022). It can be found that the surface of the 3D-printed metal is a cardinal point in the implants. The corrosion resistance of titanium alloys is due to the passive layer formed on their surface. The surface preparation of the 3D-printed sample depends on the function of the implant (Kónya, et al., 2024). In our experiments, we wanted to quantitatively and qualitatively determine the weight loss of the 3D-printed titanium alloy.

MATERIAL AND METHODS

Test specimen

The test samples were made by a fiber laser SLM device (Sisma MYSINT 100). They used parameters of 3D printing on the base of the recommendation by the Sisma company: 125 W laser power, 55 µm focus, 1000 mm/s scanning speed and 20 µm layer thickness. During the printing process, Argon shielding gas was used (35 L/min). The powder material used was plasma-spraying spherical powder (Grade 5) made by LPW Technology (Runcorn UK). The powder size distribution was between 15 µm and 45 µm, and the density was 4.43 g/cm³. The chemical composition of the powder is shown in Table 1.

Table 1. Chemical composition of the used Ti6Al4V (wt. %)

Alloy	Al	V	Fe	O	N	C	H	Ti
wt. %	6.11	4.02	0.17	0.09	0.023	0.01	0.003	Balance

The specimens were cleaned after 3D printing, without heat treatment and any surface treatments were applied. The prismatic test sample sizes were 10x7x2 mm (0.6200 g). It was used for all experiments, a new test sample of the same size and made by the same process.

The printed test sample is shown in Figure 1. The untreated surface of the printed specimen can be seen.

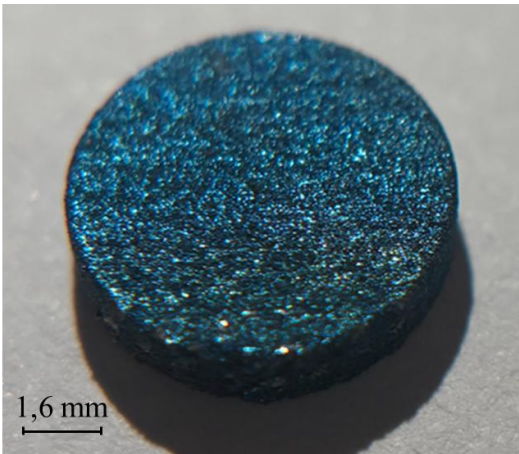


Figure 1. The used test sample geometry and size (illustration).

Weight loss corrosion test

The weight loss experiments were carried out in an aqueous sodium chloride solution (3%) at 36°C and used different durations: 4 days, 8 days, 12 days, and 16 days (on three identical samples for all time periods). After the experimental time ran out, the metal specimens were removed from the solution, washed with distilled water, and dried by airflow (Haraszi, et al.. 2022)

The weight loss was determined by Kern, AIJ 220-4MN analytical balance, with a resolution of 0.0001g.

Determination of the dissolved metal ions

An inductively coupled plasma–optical emission spectrometry (ICP-OES) was used to determine the dissolved ions in the NaCl solution in a corrosive environment. The instrument used in the investigated experiments was a Spectro Genesis ICP-OES spectrometer (with axial plasma observation). The plasma is very stable due to the unique operating frequency and broad bandwidth (wavelength range of 175–775 nm), which is equipped with a CCD detector; in this case, this method is suitable to determine about 30 elements at the same time (ranging from g/L up to percentage level).

RESULTS AND DISCUSSION

The corrosion resistance test results were evaluated using two different measurement methods. The weight loss is determined by measuring the weight (g) and identifying the dissolved ions.

Corroded material quantity determination

The corrosion level is determined by quantity measurement. The results of the weight loss measurements are shown in Table 2. It can be clearly seen that the weight loss increased during the test period. The corrosion caused a continuous weight decrease in the test samples.

Table 2. Weight loss test results in NaCl solution 3% at 36°C.

Duration (day)	Weight loss Δm (g)
4	0.0001 g
8	0.0003 g
12	0.0006 g
16	0.0013 g

The corrosion process can be described by a good approximation of the points of the obtained values. The corrosion process is characterised by the following function (1):

$$y = 6 \cdot 10^{-6} \cdot x^3 - 6 \cdot 10^{-4} \cdot x^2 + 0.0002 \tag{1}$$

Figure 2 shows the weight loss tendency as a function of the treatment time. The weight loss increases due to the NaCl solution treatment time at 36°C. The used NaCl solution was 5 mL in all tests.

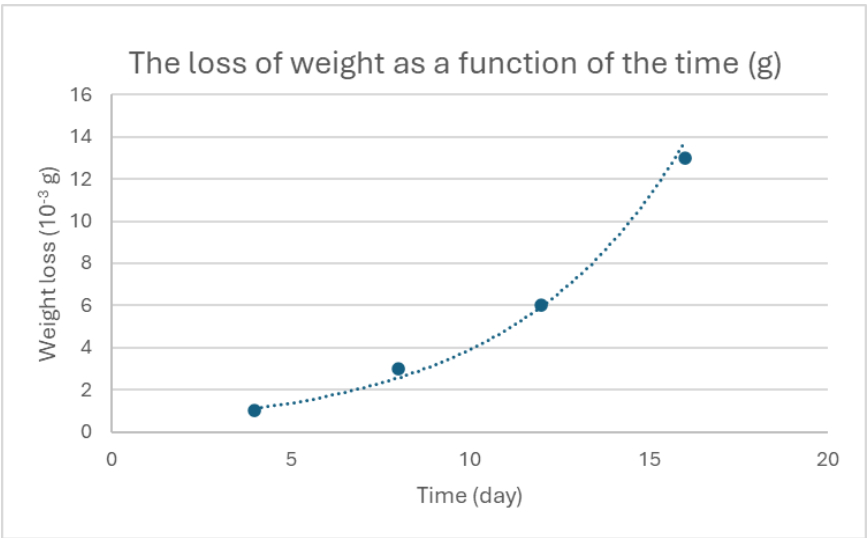


Figure 2. The weight loss as a function of time in 3% NaCl solution.

The weight loss data of the titanium alloy investigated unequivocally show that the corrosive dissolution increases over a longer time.

Corroded material quality determination

By the plasma–optical emission spectrometry method, it was determined that the dissolved elements. Only the dissolved aluminium was detected in the main elements of the alloy. Table 3 shows the dissolved aluminium quantity.

Table 3. The plasma–optical emission spectrometry results from the dissolved ions in 3% NaCl solution at 36°C.

Duration (day)	Al ions mg/L (ppm)
4	0.003
8	0.004
12	0.013
16	0.014

Figure 3 shows the dissolved aluminium ion quantity (ppm). It can be seen that the dissolution rate of the aluminium is different from the corrosion rate as a function of the weight loss (Figure 3). In the case of the aluminium dissolution, it is difficult to determine any function over time. Even the vanadium and titanium dissolution detection was impossible because of the measurement limit, but it can be supposed that the dissolution rate of the different elements of the alloy is different. It can find some research results which determine the dissolution rate of vanadium and suggest that the dissolution of vanadium begins rapidly, but after, as a function of

Kovács, T. A. et al. (2025). Sodium chloride solution test of Ti₆Al₄V implant specimens manufactured by additive technology. *STED Conference 14(2)*, 273-278.

time, the dissolution rate decreases (U.S. Department of Health and Human Services, 2025; Ghisheer, et al., 2024).

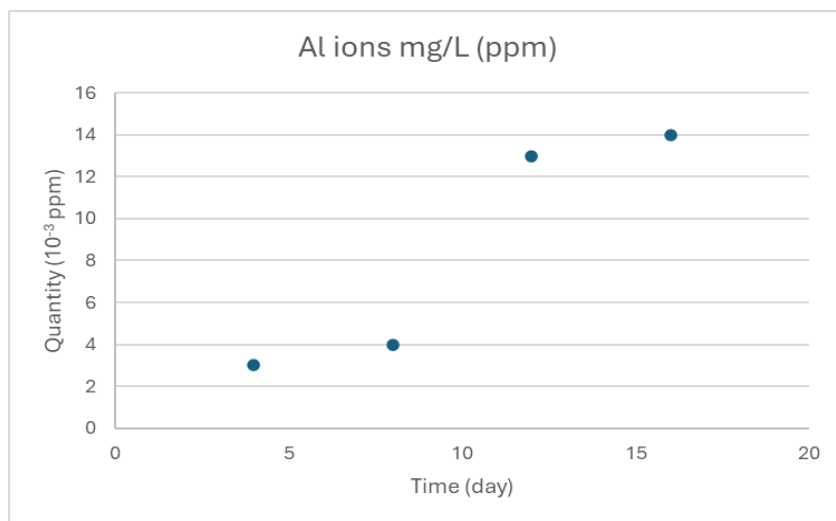


Figure 3. The weight loss as a function of time in 3% NaCl solution.

No results on aluminium leaching have been found in the literature, which was determined based on the examination of Ti₆Al₄V 3D printed implant materials. The results suggest that further, longer-term experiments are needed to determine the other elements that leach from the alloy and to understand the kinetics of corrosion. It should be noted that from the weight loss, we can only infer general corrosion, but from the amount of ion leaching, we have determined that it is the harmful aluminium that is typically present in the brine.

CONCLUSIONS

The amount and quality of material loss were determined for the alloy under investigation. Based on this, it can be concluded that the use of 3D-printed Ti₆Al₄V alloy after printing is not recommended due to the leaching of aluminium, which causes health damage. However, the roughness of the printed surface would be acceptable in terms of osseointegration. However, it needs to be investigated which of the different surface treatment methods can help prevent aluminium leaching from the 3D printed sample surface and make the implants suitable for the patients. Our aim is to continue the research by investigating the effect of different surface treatment processes on corrosion resistance.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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KORIŠĆENJE INDUSTRIJSKOG CO₂ U EOR METODAMA ZA ISKORIŠĆENJE NAFTNIH LEŽIŠTA

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SAŽETAK

Značajan deo preostale nafte u ležištima ostaje zarobljen nakon primarne i sekundarne eksploatacije, što stvara potrebu za naprednim metodama povećanja iscrpka. Jedna od efikasnijih i ekološki prihvatljivijih tehnika jeste primena industrijskog CO₂ u procesu poboljšano izdvajanja nafte (CO₂-EOR (Enhanced Oil Recovery)). U ovom radu prikazan je pregled mehanizama delovanja CO₂ na naftna ležišta, uključujući smanjenje viskoznosti, povećanje mobilnosti i postizanje miscibilnosti čime se podstiče istiskivanje zaostale nafte iz poroznog medijuma. Takođe je razmotrena mogućnost sekvenciranja CO₂, čime se ova metoda uklapa u principe održive proizvodnje energije i smanjenja emisije gasova sa efektom staklene bašte. Kroz uvid u dostupne eksperimentalne i simulacione podatke iz relevantne literature, prikazani su pozitivni efekti CO₂ ubrizgavanja: povećanje faktora iscrpka nafte do 15%, kao i smanjenje viskoznosti nafte do 80%, u poređenju sa konvencionalnim metodama. Iako postoje tehničke i ekonomske prepreke, CO₂-EOR predstavlja potencijal za produženje životnog veka naftnih ležišta i redukciju emisija gasova sa efektom staklene bašte.

Ključne reči: CO₂-EOR, industrijski CO₂, povećanje iscrpka, sekvenciranje CO₂, održiva eksploatacija.

UVOD

Nakon završetka primarne i sekundarne eksploatacije nafte, značajne količine nafte ostaju trajno zarobljene u poroznim stenskim strukturama ležišta, čime se smanjuje ukupna efikasnost eksploatacije i ekonomska isplativost proizvodnje. U cilju povećanja ukupnog faktora iscrpka, razvijene su tercijarne metode poznate kao Enhanced Oil Recovery (EOR), koje omogućavaju dodatno izdvajanje preostale nafte putem fizičko-hemijskih i mehaničkih intervencija u ležištu.

Među brojnim EOR tehnikama, ubrizgavanje ugljen-dioksida (CO₂) pokazuje značajan potencijal, jer istovremeno omogućava povećanje proizvodnje i dugoročno skladištenje CO₂, čime se doprinosi ciljevima klimatske neutralnosti. Poseban značaj ima korišćenje industrijskog (antropogenog) CO₂ — nusprodukta energetskih i industrijskih procesa — koji se umesto emitovanja u atmosferu može upotrebiti kao sredstvo za poboljšano izdvajanje nafte i sekvenciranje ugljenika u iscrpljenim rezervoarima.

Cilj ovog rada jeste da prikaže savremene pristupe korišćenju industrijskog CO₂ u EOR metodama, sa fokusom na efikasnost izdvajanja, kontrolu mobilnosti, mogućnosti geološkog skladištenja i izazove u implementaciji ove održive tehnologije.

MATERIJAL I METODE RADA

CO₂-EOR metode i mehanizmi delovanja

Uobičajeno, EOR tehnologije se dele u tri osnovne kategorije:

Termalne metode, koje uključuju primenu toplote (najčešće u obliku pare ili putem sagorevanja nafte in situ) kako bi se smanjila viskoznost sirove nafte i poboljšalo njeno kretanje kroz porozni medijum.

Hemijske metode, koje koriste polimere, surfaktante ili alkalne rastvore za poboljšanje potiskivanja nafte i smanjenje međufazne napetosti.

Radišić, B. i Prvulović, S. (2025). Korišćenje industrijskog CO₂ u EOR metodama za iskorišćenje naftnih ležišta. *STED Conference 14(2)*, 279-288.

Gasne metode, koje obuhvataju ubrizgavanje različitih gasova (CO₂, azot, prirodni gas) radi povećanja pritiska i/ili smanjenja viskoznosti nafte kroz mešanje i rastvaranje.

Među gasnim metodama, značajnu ulogu ima ubrizgavanje ugljen-dioksida (CO₂), koje pored tehničkih koristi za proizvodnju, otvara i mogućnosti za dugoročno skladištenje CO₂ u iscrpljenim rezervoarima, čime se istovremeno utiče na smanjenje emisije stakleničkih gasova. (Sečen, 2006; Strika, 2018; Arnaut, 2024).

Ubrizgavanjem CO₂ u naftno ležište postiže se niz korisnih efekata koji omogućavaju dodatno izvlačenje zaostale nafte:

- smanjenje viskoznosti sirove nafte usled rastvaranja CO₂, čime se poboljšava njena pokretljivost,
- povećanje zapremine nafte zbog širenja fluida usled apsorpcije CO₂,
- smanjenje međupovršinske napetosti između nafte i stenskog medijuma, što olakšava otpuštanje nafte sa površine stena,
- povećanje pritiska u ležištu, što dodatno doprinosi mobilizaciji nafte.

Ovi mehanizmi omogućavaju CO₂ da efikasno istiskuje preostalu naftu prema proizvodnim bušotinama, povećavajući ukupni stepen iscrpka.

Postoje tri osnovna mehanizma delovanja ubrizganog CO₂ u okviru EOR procesa:

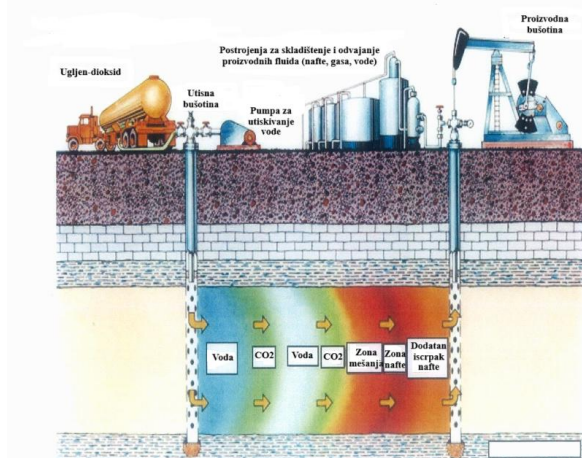
- Miscibilnost (mešljivost): CO₂ se meša sa sirovom naftom u određenim uslovima pritiska i temperature, formirajući jedinstvenu fazu sa smanjenom viskoznošću.
- Ekspanzija i karbonizacija: Rastvaranjem CO₂ u nafti dolazi do njenog bubrenja i dodatnog sniženja viskoznosti, čime se poboljšava njen transport kroz porozni medijum.
- Povećanje pritiska u rezervoaru: Ubrizgani gas povećava energiju sistema, omogućavajući pomeranje nafte ka proizvodnim bušotinama.

U praksi se primenjuju tri osnovna režima ubrizgavanja CO₂:

- Neprekidno ubrizgavanje (Continuous CO₂ Injection): CO₂ se kontinuirano ubrizgava u ležište bez prekida, čime se stvara stabilan front potiskivanja. Ova strategija je jednostavna za implementaciju, ali postoji rizik od kanalisanja CO₂ kroz visoko propusne zone, što smanjuje efikasnost izdvajanja nafte.
- WAG metoda (Water Alternating Gas): Naizmenično ubrizgavanje vode i CO₂ omogućava bolju kontrolu nad raspodelom fluida u ležištu. Voda služi kao barijera koja smanjuje kanisanje gasa, poboljšava obuhvat i povećava efikasnost istiskivanja. WAG režim se često koristi kao standardna praksa u CO₂-EOR projektima.
- Recirkulacija CO₂: Deo CO₂ koji se sa naftom vraća na površinu se hvata, odvaja, prečišćava i ponovo ubrizgava u ležište. Ova strategija doprinosi ekonomskoj održivosti procesa i omogućava veće zadržavanje CO₂ u geološkim strukturama, što dodatno doprinosi smanjenju emisije stakleničkih gasova (Al-Jarba, et al., 2010).

CO₂-WAG injekcija – efikasnost i primena

Metoda naizmeničnog ubrizgavanja ugljen-dioksida i vode (CO₂-WAG) razvijena je kako bi se kombinovale prednosti oba fluida u procesu tercijarne eksploatacije nafte. Voda povećava zapreminsku efikasnost potiskivanja, dok CO₂ poboljšava mikroskopski mehanizam istiskivanja nafte smanjenjem viskoznosti i međupovršinske napetosti. Ova sinergija omogućava značajno povećanje ukupne efikasnosti procesa. CO₂-WAG metoda funkcioniše po principu sekvencijalnog ubrizgavanja sluga CO₂ i vode, čime se postiže bolja raspodela fluida unutar ležišta i smanjuje rizik od kanalisanja CO₂ kroz visoko propusne zone. U kontrolisanim uslovima pritiska i temperature, CO₂ formira tzv. „čep rastvarača“ koji delotvorno istiskuje naftu prema proizvodnim bušotinama. Voda zatim dodatno potiskuje ovaj čep, omogućavajući veće zapreminsko pokrivanje (Al-Shargabi, et al., 2022). Princip WAG metode prikazan je na slici 1.



Slika 1. WAG metoda utiskivanja CO₂ i vode (Strika, 2018).

Prednosti WAG metode uključuju smanjenje ukupne potrošnje CO₂, ravnomernije pokrivanje fluida, posebno u slojevima sa različitom propusnošću i veću efikasnost u poređenju sa neprekidnim ubrizgavanjem CO₂. Dok su ograničenja: mogućnost gravitacionog prevazilaženja fluida i rizik od taloženja asfaltna, što zahteva dodatne hemijske tretmane. Uspešnost CO₂-WAG injekcije zavisi od više faktora:

- Minimalni pritisak za miscibilnost: CO₂ pokazuje povoljnije karakteristike u odnosu na druge gasove jer za postizanje miscibilnosti zahteva relativno niži pritisak.
- Dubina ležišta: Ležišta plića od 760 m često ne mogu obezbediti dovoljan pritisak za stabilno ubrizgavanje CO₂.
- Svojstva nafte: Optimalni rezultati se postižu kod nafte manje gustine (<921 kg/m³, tj. >22°API).
- Heterogenost ležišta: Visoka heterogenost (npr. slojevitost struktura, frakture) može dovesti do neujednačenog toka fluida i smanjene efikasnosti metode.

Metoda CO₂-WAG ubrizgavanja predstavlja tehnološki i ekonomski održiv pristup povećanju iscrpka nafte, naročito u ležištima sa povoljnim litološkim i fizičko-hemijskim karakteristikama. Pravilna analiza uslova ležišta, kombinovana sa optimalnim odnosom CO₂ i vode, omogućava povećanje efikasnosti, bolju kontrolu toka fluida i dugoročnu mogućnost skladištenja CO₂ u geološkim formacijama (Massarweh, et al., 2022).

Kontrola mobilnosti CO₂ – izazovi i rešenja

Uprkos značajnim prednostima koje CO₂-EOR metoda donosi u pogledu povećanja iskorišćenja nafte i mogućnosti trajnog skladištenja ugljen-dioksida u iscrpljenim rezervoarima, jedan od ključnih izazova u njenoj primeni predstavlja narušena kontrola mobilnosti CO₂ u poroznom medijumu. Specifična fizičko-hemijska svojstva CO₂, naročito njegova niska viskoznost i sklonost ka brzom kretanju kroz visoko propusne zone, često dovode do pojave kanalisanja i prstastog toka, što umanjuje kontakt sa naftom i snižava efikasnost istiskivanja. Osim toga, gravitaciona segregacija dodatno pogoršava raspodelu fluida u vertikalnom profilu ležišta, jer lakši CO₂ teži ka gornjim delovima formacije, izbegavajući dublje delove rezervoara u kojima se nafta zadržava. Zaključno, efikasna kontrola mobilnosti CO₂ predstavlja ključni aspekt uspeha CO₂-EOR metoda. Kombinacijom hemijskih, digitalnih i inženjerskih rešenja, moguće je prevazići postojeće izazove i postići dvostruki cilj – povećanje proizvodnje i smanjenje emisija CO₂. Dalji razvoj i sinergija tehnologija u oblasti digitalizacije, nanotehnologije i energetske tranzicije otvaraju nove mogućnosti za održivu eksploataciju nafte u 21. veku.

Autori Massarweh, & Abushaikha, (2022) navode različite metode koje se koriste kako bi se poboljšala kontrola mobilnosti CO₂ i povećala efikasnost njegovog potiskivanja:

- dodavanje polimera – polimeri povećavaju viskoznost CO₂ i poboljšavaju njegovu sposobnost potiskivanja nafte,
- pena stabilizovana surfaktantima – ubrizgavanje pene na bazi CO₂ poboljšava distribuciju gasa u ležištu i smanjuje efekat prstastog toka,
- hibridne metode – kombinacija CO₂ s drugim metodama, poput hemijskih i toplinskih tehnika, povećava ukupnu efikasnost izdvajanja,
- nanočestice u kombinaciji s CO₂ – istraživanja pokazuju da nanočestice mogu poboljšati stabilnost CO₂ pene i poboljšati kontrolu mobilnosti,
- upotreba nečistog CO₂ iz industrijskih izvora – analizira se kako prisustvo drugih gasova u industrijskom CO₂ može uticati na performanse EOR metoda.

Pored toga, naglašavaju da je kontrola mobilnosti CO₂ ključna za poboljšanje efikasnosti EOR metoda i da se najefikasniji pristupi trenutno baziraju na peni stabilizovanoj surfaktantima i upotrebi polimera.

Kombinacija sa drugim metodama i savremenim tehnološkim rešenjima može dodatno poboljšati efikasnost eksploatacije i smanjiti operativne troškove. Napredak u tehnologiji značajno je unapredio primenu ovih metoda:

Real-time simulacije (simulacija ležišta u realnom vremenu): Predviđaju kretanje gasa i optimizuju parametre injekcije. Donošenje odluka na osnovu realnih podataka smanjuje rizik eksperimentalnih pristupa i povećava efikasnost.

4D seizmički monitoring: Prati promene u ležištu tokom vremena, pružajući jasan uvid u kretanje fluida i gasa unutar rezervoara i omogućavajući prilagođavanje strategija.

Pametne bušotine: Kontinuirano prate pritisak, temperaturu i kompoziciju fluida, pomoću senzora koji u realnom vremenu mere parametre. Ovi podaci omogućavaju preciznu kontrolu procesa eksploatacije i optimizaciju gasne injekcije.

AI (veštačka inteligencija) i mašinsko učenje: Optimizuju procese analizom velikih količina podataka i automatskim podešavanjem parametara. Ova automatizacija smanjuje mogućnost ljudskih grešaka, ubrzava proces donošenja odluka i poboljšava ukupnu efikasnost eksploatacije.

Savremeni CO₂-EOR projekti sve više integrišu digitalne tehnologije kako bi se povećala efikasnost izdvajanja nafte uz istovremeno trajno skladištenje CO₂. Ključni izazov u ovim projektima je postizanje ravnoteže između dva cilja: maksimizacije proizvodnje nafte i maksimizacije količine trajno uskladištenog ugljen-dioksida. Upravo zbog te međuzavisnosti, u planiranju i upravljanju EOR procesima sve češće se koriste napredne metode optimizacije, modelovanja i analize rizika. Tradicionalni pristupi podrazumevaju ručnu selekciju operativnih parametara, što je sporo, podložno greškama i često zanemaruje promene koje se dešavaju tokom vremena. Tehnološki napredak je značajno poboljšao efikasnost gasnih EOR metoda, smanjujući troškove i ekološki uticaj eksploatacije. Simulacija ležišta u realnom vremenu, 4D seizmičko praćenje, pametne bušotine i veštačka inteligencija omogućavaju precizniju kontrolu nad procesom i povećavaju uspešnost eksploatacije. Dalji razvoj ovih tehnologija donosi još veće mogućnosti za optimizaciju proizvodnje iz zrelih i kompleksnih ležišta, čineći industriju nafte i gasa efikasnijom i održivijom (Ampomah, et al., 2017).

Budućnost gasnog EOR-a zavisi od primene održivih praksi, uključujući razvoj bio-gasova i ekološki prihvatljivih tehnika, kao i usklađivanje sa sve strožim regulatornim zahtevima. Na primer, istražuju se metode poput mikrobnog EOR-a, gde se ubrizgavaju hranljive materije kako bi se stimulisao rast mikroorganizama koji pomažu u mobilizaciji nafte. Takođe, sve veći fokus je na hvatanju i skladištenju ugljen-dioksida (Carbon Capture and Storage - CCS) radi smanjenja ekološkog uticaja CO₂-EOR projekata. Zaključno, budući napredak u gasnom EOR-u leži u inovacijama, industrijskoj saradnji i održivim praksama, što će omogućiti efikasniju eksploataciju nafte uz smanjenje ekološkog otiska (Ozowe, et al., 2024). U poslednjim godinama, postizanje ugljenične neutralnosti postalo je ključni globalni cilj, posebno nakon potpisivanja Pariskog sporazuma iz 2015. godine, kojim se nastoji ograničiti globalno zagrevanje na ispod 2°C do kraja

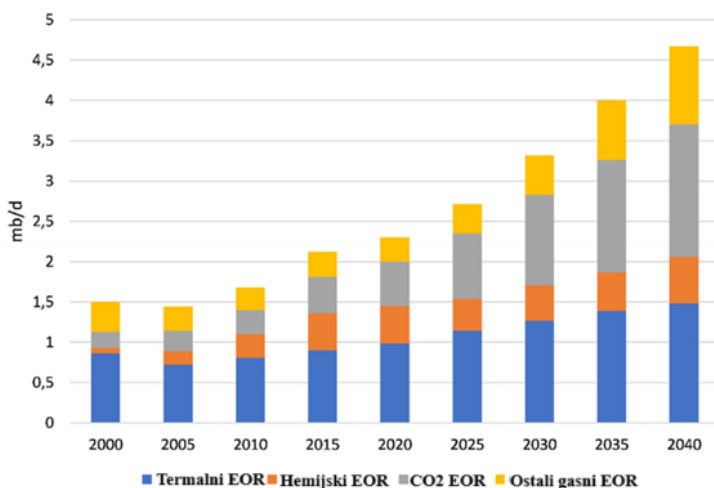
Radišić, B. i Prvulović, S. (2025). Korišćenje industrijskog CO₂ u EOR metodama za iskorišćenje naftnih ležišta. *STED Conference 14(2)*, 279-288.

21. veka. Mnoge zemlje, uključujući Evropsku uniju, Sjedinjene Američke Države i Kinu, postavile su svoje ciljeve i akcione planove za smanjenje emisija ugljen-dioksida (CO₂). Na primer, EU planira da postigne ugljeničnu neutralnost do 2050. godine, dok Kina planira da dostigne vrhunac emisija do 2030. a zatim da do 2060. ostvari neutralnost. Kako bi se ublažile posledice globalnog zagrevanja, razvijene su tehnologije za hvatanje i skladištenje ugljen-dioksida (CCS). Jedna od najzanimljivijih metoda skladištenja CO₂ jeste ona koja se kombinuje sa poboljšanim izdvajanjem nafte – CO₂-EOR (enhanced oil recovery). Suština ove metode je da se industrijski CO₂, koji bi inače bio ispušten u atmosferu, ubrizgava u istrošena naftna ležišta kako bi se istisnula preostala nafta i istovremeno skladištio CO₂. Time se spaja ekonomska dobit (povećanje eksploatacije) sa ekološkom koristi (smanjenje emisija). Cilj ovog rada jeste da se razmotri održivost ove tehnologije kao sredstva za dugoročno skladištenje CO₂ i doprinos borbi protiv klimatskih promena (Shiyi, et al., 2022; Farajzadeh, et al., 2020).

Posebno se ističe kombinacija EOR metoda sa CCUS konceptom (Carbon Capture, Utilization and Storage), gde se industrijski CO₂ koristi i za poboljšanje proizvodnje nafte i za trajno skladištenje gasova sa efektom staklene bašte. CCUS predstavlja hvatanje, upotrebu i skladištenje ugljen-dioksida, koji je širi koncept od CCS-a, jer podrazumeva i upotrebu CO₂. Ipak, određeni faktori i dalje ograničavaju širu primenu ove metode. To su:

- nedostatak izvora visokokoncentrovanog CO₂ u blizini ležišta, što povećava logističke troškove,
- visoka cena hvatanja CO₂ iz niskokoncentrovanih izvora, kao što su termoelektrane,
- ograničeni kapaciteti za dugolinijski transport CO₂, jer su gasovodne mreže još u razvoju,
- nedostatak iskustva sa dugoročnim nadzorom bezbednosti skladišta CO₂, iako do sada nije zabeležen nijedan slučaj curenja (Shiyi, et al., 2022).

Problem kod CO₂-EOR metoda jeste nedostatak industrijskih izvora CO₂ blizu naftnih polja i visoki troškovi za hvatanje, transport i skladištenje CO₂. Iako SAD imaju razvijenu infrastrukturu (preko 13.000 bušotina i 5.600 km cevovoda), šira primena u svetu je ograničena. Kao rešenje se razvija tehnologija za „in situ“ (na licu mesta) generaciju CO₂ u ležištu pomoću hemijskih reakcija, što smanjuje troškove i rizike povezane s transportom. Takva tehnologija omogućava bolju kontrolu nad količinom i pritiskom CO₂ i efikasnije izvlačenje nafte iz „mrtvih zona“ ležišta. Kao što se vidi na slici 2, ukupna količina nafte dobijena EOR metodama raste, a naročito raste udeo CO₂ i gasnih metoda, što potvrđuje značaj inovacija poput „in situ“ CO₂ generacije (Panahov, et al., 2021).



Slika 2. Stvarna i prognozirana raspodela modela za povećanje iscrpka nafte (Panahov, et al., 2021).

Korišćenje industrijskog CO₂ – izvori i izazovi

Jedan od ključnih izazova u primeni tehnologije CO₂-EOR u savremenim uslovima odnosi se na poreklo i dostupnost samog ugljen-dioksida. Iako se konceptualno podrazumeva da se za poboljšano izdavanje nafte može koristiti industrijski (antropogeni) CO₂, realna primena još uvek u značajnoj meri zavisi od prirodnih izvora ovog gasa. Prema Farajzadehu i saradnicima (2020), većina CO₂ koji se danas koristi u EOR projektima potiče iz prirodnih podzemnih nalazišta, a ne iz industrijskih postrojenja, i to uprkos činjenici da veliki broj antropogenih izvora CO₂ postoji širom sveta. Industrijski izvori CO₂ uključuju termoelektrane na fosilna goriva, rafinerije, cementare, čeličane i hemijsku industriju. Među njima, termoelektrane su najznačajniji emitenti zbog velikog obima sagorevanja uglja, nafte i prirodnog gasa. Emisije CO₂ po jedinici energije značajno se razlikuju u zavisnosti od vrste goriva – sagorevanje prirodnog gasa (metan, CH₄) emituje približno 0,055 kg CO₂/MJ, nafta (CH₂) oko 0,073 kg CO₂/MJ, dok sagorevanje uglja (CH) generiše i do 0,088 kg CO₂/MJ. Ove brojke ukazuju na ogroman tehnički potencijal za hvatanje CO₂ iz industrijskih procesa, naročito iz sektora energetike. Ipak, tehnički potencijal nije dovoljan za komercijalnu primenu. Glavni razlog za to leži u visokim energetske i finansijskim troškovima izdavanja CO₂ iz dimnih gasova, što znatno utiče na isplativost EOR projekata koji se oslanjaju na industrijski CO₂. Trenutno najčešće korišćena tehnologija za separaciju CO₂ je hemijska apsorpcija pomoću monoetanolamina (MEA). Ova metoda, iako efikasna u pogledu čistoće izdvojenog CO₂, zahteva prosečno oko 4000 kJ egzergije po kilogramu CO₂, što predstavlja od 30% do 50% energije sadržane u gorivu (zavisno od vrste goriva). U kontekstu komercijalne proizvodnje nafte, ovi gubici čine korišćenje antropogenog CO₂ manje konkurentnim u odnosu na prirodno dostupne izvore (Farajzadeh, et al., 2020).

Još jedan ključan izazov ogleda se u geografskoj neskladnosti između izvora emisije i naftnih ležišta pogodnih za EOR. Naime, termoelektrane, cementare i druga postrojenja najčešće se nalaze u blizini potrošačkih centara i industrijskih zona, dok se naftna i gasna polja često nalaze u udaljenim ili ruralnim oblastima. Zbog toga se javlja potreba za izgradnjom specijalizovane infrastrukture za transport CO₂, kao što su gasovodi na velike razdaljine i kompresorske stanice za održavanje CO₂ u superkritičnom stanju. Ovi dodatni infrastrukturni zahtevi ne samo da povećavaju kapitalne troškove, već i uvode dodatne energetske gubitke i kompleksnost u operativno upravljanje projektom. Uprkos ovim ograničenjima, korišćenje industrijskog CO₂ ima višestruke prednosti, naročito u kontekstu ublažavanja klimatskih promena. Industrijski CO₂, koji bi inače bio emitovan u atmosferu, u okviru EOR metoda može biti trajno uskladišten u iscrpljenim naftnim rezervoarima, čime se direktno doprinosi konceptu karbonske neutralnosti. Zbog toga se upotreba antropogenog CO₂ u EOR projektima posmatra kroz prizmu CCUS strategije (Carbon Capture, Utilization and Storage), koja ima dvostruku korist: omogućava povećanje proizvodnje nafte iz zrelih ležišta i istovremeno doprinosi smanjenju emisija CO₂ u atmosferu (Shiyi, et al., 2022).

Prema Kirchofer, et al. (2013), industrijski alkalni otpad – poput letećeg pepela, cementne prašine i metalurške šljake – ne samo da predstavlja potencijalne izvore za hemijsku sekvencijaciju CO₂ putem mineralne karbonacije, već istovremeno rešava problem odlaganja otpada. Ovi nusprodukti nastaju upravo u industrijama koje su značajni emiteri CO₂ – kao što su termoelektrane, cementare i čeličane – i zato predstavljaju logičan spoj sa CCUS projektima, uključujući EOR metode (Kirchofer, et al., 2013).

REZULTATI I DISKUSIJA

U ovom poglavlju prikazani su sažeti rezultati iz relevantne literature koji ilustruju efekte primene CO₂-EOR metoda, sa posebnim naglaskom na uticaj industrijskog CO₂ na povećanje faktora iscrpka, smanjenje viskoznosti sirove nafte i potencijal geološkog skladištenja. Prikazani podaci predstavljaju aproksimacije dobijene na osnovu terenskih studija i laboratorijskih istraživanja, sa ciljem da se prikaže efektivnost tehnologije u različitim uslovima eksploatacije. Poređenja metoda ubrizgavanja, analiza reoloških promena i primeri iz konkretnih projekata daju uvid u realni potencijal i izazove upotrebe industrijskog CO₂ u savremenim EOR projektima.

Efikasnost metoda ubrizgavanja CO₂

U okviru CO₂-EOR metoda, primenjuju se dve osnovne šeme ubrizgavanja: kontinuirano ubrizgavanje CO₂ i WAG režim. Kontinuirano ubrizgavanje karakteriše jednostavna implementacija, jer podrazumeva neprekidno unošenje CO₂ u ležište. Međutim, zbog niskog odnosa viskoznosti između CO₂ i nafte, ovaj pristup često dovodi do kanalisanja gasa, proboja kroz propusnije zone i slabije zapreminske pokrivenosti ležišta. Rezultat je smanjena efikasnost izdvajanja nafte i povećani gubici CO₂. Nasuprot tome, WAG režim omogućava bolju kontrolu mobilnosti fluida, smanjuje gubitke CO₂ i poboljšava distribuciju u poroznom prostoru. Studije pokazuju da WAG režim može poboljšati ukupnu efikasnost izdvajanja nafte za 10–15% u odnosu na kontinuirani režim, pri jednakim količinama ubrizganog CO₂. U tabeli 1 prikazana je uporedna analiza ovih dveju metoda.

Tabela 1. Uporedna analiza kontinuiranog ubrizgavanja i WAG metode.

Aspekt	Kontinuirano ubrizgavanje CO ₂	WAG metoda
Efikasnost pomeranja	Niska	Visoka
Gubitak CO ₂	Veći	Manji
Pokrivenost ležišta	Smanjena	Poboljšana
Tehnička složenost	Niža	Viša

Uticaj CO₂ na viskoznost nafte

Jedan od ključnih mehanizama koji doprinosi efikasnosti CO₂-EOR metoda jeste smanjenje viskoznosti nafte usled rastvaranja CO₂ u tečnoj fazi. Kada se CO₂ ubrizga pod visokim pritiskom u rezervoar, on se rastvara u nafti, što dovodi do značajnog smanjenja unutrašnjeg trenja između molekula nafte i povećava njenu mobilnost. Eksperimentalni podaci pokazuju da pri različitim temperaturama dolazi do smanjenja viskoznosti nafte za 40–50%, što direktno utiče na lakše pomeranje nafte ka proizvodnim bušotinama. U tabeli 2 prikazano je smanjenje viskoznosti u odnosu na temperaturu nakon ubrizgavanja CO₂.

Tabela 2. Smanjenje viskoznosti posle CO₂.

Temperatura (°C)	Viskoznost pre CO ₂ (Cp)	Viskoznost posle CO ₂ (Cp)	Smanjenje (%)
30°C	8,0	4,5	43,8%
50°C	6,2	3,2	48,4%
70°C	4,0	2,1	47,5%

Ovi rezultati potvrđuju da rastvaranje CO₂ u nafti ima značajan uticaj na njenu reološku strukturu, pri čemu dolazi do smanjenja viskoznosti čak i pri umerenim temperaturnim uslovima. Ovakvo ponašanje CO₂ doprinosi poboljšanju mikroskopske efikasnosti pomeranja, što je posebno značajno u ležištima sa viskoznijom naftom. Smanjena viskoznost omogućava bolji kontakt između fluida za potiskivanje i rezidualne nafte, kao i lakše savladavanje kapilarnih sila unutar porozne sredine. Rastvaranje CO₂ u nafti predstavlja jedan od osnovnih mehanizama poboljšanja pomeranja u CO₂-EOR metodama. Efekat sniženja viskoznosti, koji u nekim slučajevima prelazi 45%, u velikoj meri doprinosi povećanju faktora iscrpka, posebno u fazama kada su rezerve već delimično iscrpljene prethodnim metodama.

Povećanje faktora iscrpka primenom CO₂

Primena CO₂ u projektima povećanja iscrpka ne donosi samo ekonomske koristi kroz dodatnu proizvodnju nafte, već omogućava i dugoročno zadržavanje značajnih količina ugljen-dioksida u podzemnim formacijama. Terenske studije pokazuju da se faktori iscrpka mogu povećati za 10 do

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25% u odnosu na prethodni režim vodnog potiskivanja, u zavisnosti od tipa ležišta, dubine, režima ubrizgavanja i svojstava fluida. Istovremeno, značajan deo ubrizganog CO₂ ostaje trajno zarobljen u ležištu, što ovaj proces čini relevantnim i u kontekstu ublažavanja klimatskih promena, posebno kada se uklopi u koncept CCUS tehnologija. U tabeli 3 predstavljeno je, na konkretnim primerima, povećanje faktora iscrpka (Recovery Faktor–RF) nakon CO₂.

Tabela 3. Povećanje faktora iscrpka.

Ležište	Početni RF (%)	RF posle CO ₂	Povećanje (%)
Weyburn (Kanada)	35%	56%	+21%
Shengli (Kina)	30%	47%	+17%
Garber (SAD)	33%	44%	+11%
Ležišta A (SAD)	30%	48%	+18%
Ležište B (Bliski istok)	28%	44%	+16%
Ležište C	25%	40%	+15%

U projektu Weyburn (Kanada), koji je jedan od najpoznatijih primera kombinovanog EOR i CO₂ skladištenja, ostvaren je porast faktora iscrpka za 21%, uz trajno zadržavanje preko 90% ubrizganog CO₂ u rezervoaru. Slični rezultati zabeleženi su i u Shengli ležištu u Kini i Uthmaniyah u Saudijskoj Arabiji, gde su tehnički rezultati bili zadovoljavajući, a istovremeno je omogućeno smanjenje emisija CO₂ u atmosferu. Takvi primeri potvrđuju da je uz adekvatnu kontrolu pritiska, optimizaciju režima ubrizgavanja (npr. WAG) i stabilnost zatvorenog rezervoarskog sistema, moguće istovremeno ostvariti energetske i ekološke ciljeve. CO₂-EOR metode imaju potencijal da istovremeno unaprede energetski bilans i doprinesu klimatskoj neutralnosti, naročito kada se baziraju na upotrebi industrijskog CO₂. Tereni podaci jasno ukazuju na dvostruki efekat – povećanje iscrpka i trajnu sekvencijaciju CO₂, čime ova tehnologija zadobija važnu ulogu u tranziciji ka održivoj proizvodnji energije. Primeri su preuzeti iz preglednih i tehničkih studija: Ajayi, et al. (2019), Massarweh, & Abushaikh (2022), Panahov, et al. (2021).

ZAKLJUČCI

Primena industrijskog CO₂ u EOR metodama predstavlja efikasan spoj energetske dobitnosti i ekološke održivosti. Ova tehnologija omogućava dodatno izdvajanje nafte iz iscrpljenih ležišta i istovremeno omogućava dugoročno skladištenje CO₂, čime doprinosi ciljevima smanjenja emisija i klimatske neutralnosti.

Korišćenjem režima ubrizgavanja poput WAG metode, uz savremene pristupe kontroli mobilnosti CO₂ (polimeri, pena, nanočestice), može se značajno povećati faktor iscrpka i stabilnost procesa. Implementacija digitalnih rešenja kao što su real-time simulacije, pametne bušotine i AI alati dodatno povećava operativnu efikasnost i sigurnost eksploatacije.

Ipak, izazovi poput visokih troškova separacije CO₂, ograničene dostupnosti izvora blizu ležišta i potrebe za infrastrukturom za transport CO₂ i dalje ograničavaju punu primenu ove metode. Razvoj tehnologija za in situ generaciju CO₂, kao i usklađivanje sa regulativama i klimatskim politikama, ključni su koraci ka široj primeni.

Zaključno, integracija CO₂-EOR metoda u širi koncept CCUS strategije može doprineti transformaciji naftne industrije u pravcu održivog razvoja i energetske tranzicije.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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UTILIZATION OF INDUSTRIAL CO₂ IN EOR METHODS FOR ENHANCED OIL RECOVERY

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ABSTRACT

A significant portion of oil remains trapped in reservoirs after primary and secondary recovery, creating the need for advanced enhanced oil recovery (EOR) techniques. One of the more efficient and environmentally friendly methods is the use of industrial CO₂ in the enhanced oil recovery process (CO₂-EOR). This paper provides an overview of the mechanisms through which CO₂ interacts with oil reservoirs, including viscosity reduction, improved mobility, and the achievement of miscibility, all of which promote the displacement of residual oil from the porous medium. The potential for CO₂ sequestration is also considered, making this method compatible with the principles of sustainable energy production and greenhouse gas emission reduction. Based on available experimental and simulation data from relevant literature, the positive effects of CO₂ injection are highlighted: oil recovery factor increases of up to 15%, and viscosity reductions of up to 80% compared to conventional methods. Despite technical and economic challenges, CO₂-EOR presents a promising opportunity to extend the productive life of oil reservoirs and reduce greenhouse gas emissions.

Keywords: CO₂-EOR, industrial CO₂, enhanced recovery, CO₂ sequestration, sustainable exploitation.

INTERACTIONS OF HUMAN SERUM ALBUMIN WITH A PALLADIUM(II) COMPLEX CONTAINING A THIOAMIDE MOIETY: DETAILED EXPERIMENTAL AND MOLECULAR DOCKING STUDIES

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ABSTRACT

Thioamides and their derivatives are an interesting group of compounds because of their structural variations and also because of the combination of hard and soft donor atoms (S and N) that potentially allow coordination – in a variety of binding modes – to a wide range of metal centers, and also because of their biological significance.

In our previous studies, we have synthesized a palladium(II) complex with a thioamide-type ligand of the formula $[PdL_2Cl_2]$ (L= ethyl 4-[1-amino-2-cyano-3-(methylamino)-3-thioxo-1-propen-1-yl]-1-piperazine-1-carboxylate), whose ability to interact with DNA was investigated fluorometrically. In this work, research was continued in the direction of studying the interactions of the thioamide ligand and its palladium(II) complex with human serum albumin (HSA) in the presence of site-specific markers: warfarin (site I, subdomain IIA), ibuprofen (site II, subdomain IIIA) or methyl orange (site III, subdomain IB), to determine the binding affinity, binding strength and the location of binding site. The results obtained showed that ligand and complex bind moderately to the HSA via site III (subdomain IB), and that the quenching mechanism is static.

Keywords: palladium(II), thioamide, HSA interaction, competitive binding studies, docking simulation.

INTRODUCTION

Thioamides, as sulfur-containing analogs of amides, represent a structurally diverse class of compounds with intriguing chemical and biological properties. Their ability to coordinate with transition metal ions arises from the presence of both soft (S) and hard (N) donor atoms, which enable different binding modes and geometries (Reiss et al., 2012; Desseyn, 1989). These structural features, as well as the pharmacophoric potential of thioamides, have attracted considerable attention in medicinal and coordination chemistry, particularly in the development of metal-based therapeutic agents (Nadeem et al., 2010; Ahmad et al., 2017). Among the transition metal complexes, palladium(II) compounds have attracted considerable interest due to their structural and electronic similarity to platinum(II) analogs, many of which are known chemotherapeutic agents (Matesanz et al., 2013). However, Pd(II) complexes often exhibit greater kinetic lability compared to Pt(II), which can affect their reactivity, biological stability and interaction dynamics with biomolecules. Understanding such interactions is crucial for evaluating the pharmacological potential of these complexes.

Human serum albumin (HSA), the most abundant plasma protein in humans, plays a central role in the transport, metabolism, and distribution of a variety of endogenous and exogenous substances, including drugs, hormones, and metal ions (Mitrović et al., 2024). HSA possesses multiple binding sites, in particular Sudlow's sites I and II (located in subdomains IIA and IIIA, respectively), and a third site in subdomain IB, which can serve as a binding region for small molecules and metal complexes (Mitrović et al., 2024; Zsila, 2013). Investigating the binding

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properties of metal-based drugs to HSA is crucial for understanding their in vivo behavior, distribution, and potential side effects (Mitrović et al., 2024; Zsila, 2013).

In our previous work, we reported the synthesis and DNA-binding activity of a Pd(II) complex with a thioamide-type ligand, ethyl 4-[1-amino-2-cyano-3-(methylamino)-3-thioxo-1-propen-1-yl]-1-piperazine-1-carboxylate, forming the complex [PdL₂Cl₂] (Ristić i sar., 2024). Building on this basis, the interactions of this ligand and its Pd(II) complex with HSA are investigated in the present study. In addition, molecular docking simulations were used to obtain an atomistic insight into the binding interactions and to support the spectroscopic results.

MATERIAL AND METHODS OF WORK

Protein binding studies were performed with human serum albumin (HSA) in PBS buffer (10 mM PBS, pH 7.4), using a fixed HSA concentration and varying compound concentrations. The quenching of the emission intensity of HSA tryptophan residues at 361 nm was monitored using the investigated compounds as quenchers with increasing concentrations. Fluorescence spectra were recorded from 300 to 500 nm at an excitation wavelength of 295 nm. We also investigated the competitive interactions between the markers (warfarin as marker for site I of subdomain IIA, ibuprofen as marker for site II of subdomain IIIA and methyl orange as marker for site III of subdomain IB) and the compounds towards HSA using the same method as above. The fluorescence spectra of the investigated compounds were recorded under the same experimental conditions, and no fluorescence emission was detected. The relevant constants were calculated using the Stern–Volmer and Scatchard equations (1) and (2) and plots (Lakowicz, 2006):

$$F_0/F = 1 + k_q \tau_0 [Q] = 1 + K_{sv}[Q] \quad (1)$$

where F_0 is the emission intensity in the absence of the compound, F is the emission intensity in the presence of the compound, K_{sv} is the Stern–Volmer quenching constant, k_q is the bimolecular quenching constant, τ_0 (10^{-8} s) (Lakowicz and Weber, 1973) is the lifetime of the fluorophore in the absence of the quencher, and $[Q]$ is the concentration of the quencher (compound). The K_{sv} value is determined as the slope from the plot of F_0/F versus $[Q]$.

$$\log (F_0 - F)/F = \log K_b + n \log [Q] \quad (2)$$

The values of K_b and n were determined from the intercept and slope of the plots of $\log (F_0 - F)/F$ vs. $\log [Q]$.

COMPUTATIONAL RESEARCH

Dft calculations

In all tested compounds B3LYP functional (Zhang et al., 2005; Lashgari et al., 2005) was used to optimize the geometries together with LANL2DZ basis set. The structures were visualized in a free version of the Discovery Studio Visualizer 3.5.0 Accelrys Software Inc. (<https://www.3ds.com/products/biovia>). These calculations were performed by Gaussian 09 program package (Frisch et al., 2013).

Molecular docking

The X-ray crystal structure of HSA (PDB ID: 1HK1) was acquired from the Protein Data Bank (PDB) ([RCSB PDB: Homepage](#)). Docking processes were carried out using Autodock 4.2 (Morris et al., 2009) software equipped with the graphical user interface (GUI) Auto-DockTools (ADT 1.5.6rc3) (Sanner et al., 2009). Then the polar hydrogen atoms were added, and ADT was used to remove crystal water, Geisteiger charges were added to each atom, and merge non-polar hydrogen atoms to the DNA structure. The structures were then saved in PDBQT file format, for further studies in ADT. For the visualization of the docking results, a free version of the Discovery

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Studio Visualizer 3.5.0 Accelrys Software Inc. (<https://www.3ds.com/products/biovia>) so as Chimera software have been used (<https://www.rbvi.ucsf.edu/chimera>).

RESULTS AND DISCUSSION

In order to localize the exact binding site of the investigated compounds to the HSA molecule, competitive experiments were performed with the above-mentioned markers. The binding site markers and HSA were added in equimolar concentrations (2 μM), while the ligand and complex solutions were added in increasing concentrations up to a ratio of 10 (up to 20 μM). The obtained fluorescence data were analyzed using the Stern–Volmer and Scatchard equations and plots (Figs. 1 and 2, equations (1) and (2)). The Stern–Volmer constants (K_{SV}), biomolecular quenching constants (k_q) and binding constants (K_b) for the interactions of investigated compounds with HSA in the presence and absence of the site markers are listed in Table 1. The HSA–ibuprofen, HSA–warfarin and HSA–methyl orange (Fig. 2) adducts show intense emission that decreases with the addition of the studied compounds, and the results show that the studied compounds bind with moderately strong affinity ($K_b = 10^2\text{--}10^4 \text{ M}^{-1}$) to sites IIA, IIIA and IB.

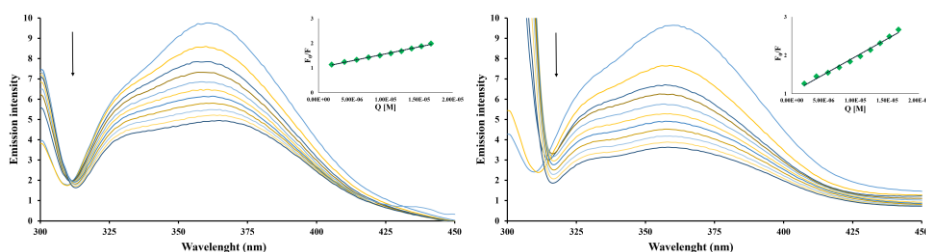


Figure 1. Fluorescence emission spectra of HSA in the presence of different concentrations of the ligand (left) and complex (right) ($T = 298 \text{ K}$, $\text{pH} = 7.4$). $[\text{HSA}] = 2.0 \mu\text{M}$. $[\text{Compound}] = 0\text{--}20 \mu\text{M}$. The arrow shows the change in intensity as the complex concentration is increased. Inset: plot of F_0/F versus [compound].

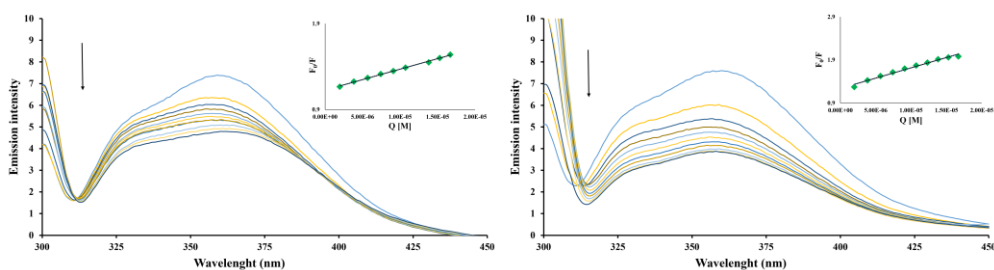


Figure 2. Fluorescence emission spectra of HSA in the presence of different concentrations of the ligand (left) and complex (right) with specific marker MO ($T = 298 \text{ K}$, $\text{pH} = 7.4$). $[\text{HSA}] = [\text{MO}] 2.0 \mu\text{M}$. $[\text{compound}] = 0\text{--}20 \mu\text{M}$. The arrow shows the change in intensity as the complex concentration is increased. Inset: plot of F_0/F versus [compound].

The binding constants were observed to change and decrease in the presence of the site markers, with the largest decrease observed in the presence of methyl orange, suggesting that the complexes may compete with this site marker and bind to site IB. However, slight changes in the constants in the presence of the other two site markers (warfarin and ibuprofen) cannot be completely ignored. For this reason, docking experiments are also performed in this study.

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Table 1. HSA constants (K_{sv} , k_q , K_b) and number of binding sites (n) for the interactions of L and PdL in the absence and the presence of site markers.

System	K_{sv} (M ⁻¹)	k_q (M ⁻¹ s ⁻¹)	K_b (M ⁻¹)	n
L-HSA	5.63×10^4	5.63×10^{12}	2.29×10^4	0.92
L-HSA-WF	3.38×10^4	3.38×10^{12}	8.12×10^2	0.64
L-HSA-IP	4.84×10^4	4.84×10^{12}	4.46×10^4	1.0
L-HSA-MO	2.43×10^4	2.43×10^{12}	2.05×10^2	0.55
PdL-HSA	9.31×10^4	9.31×10^{12}	1.80×10^4	0.85
PdL-HSA-WF	7.16×10^4	7.16×10^{12}	3.86×10^3	0.72
PdL-HSA-IP	4.83×10^4	4.83×10^{12}	2.07×10^3	0.71
PdL-HSA-MO	4.77×10^4	4.77×10^{12}	7.58×10^2	0.60

Docking results

Calculated data of the molecular docking are represented in Table 2. In case of ligand L (with BSA) values of ΔG for three binding sites are: IIA = -7.98 kcal·mol⁻¹, IIIA = -5.99 kcal·mol⁻¹ and IB = -6.75 kcal·mol⁻¹. Further, PdL compound gave lower negative energy values (IIA = -7.00 kcal·mol⁻¹, IIIA = -5.89 kcal·mol⁻¹ and IB = -7.15 kcal·mol⁻¹).

Table 2. Overview of molecular docking calculations for L and PdL with HSA.

Compound	ΔG (kcal mol ⁻¹)		
	IIA	IIIA	IB
L	- 6.71	- 5.99	- 6.75
PdL	- 7.00	- 5.89	- 7.15

Thus, the represented data (Table 2) predicts stronger binding to HSA in the case of the PdL complex system. The best docking poses are presented in Figure 3, left (between L and HSA) and Figure 3, right (between PdL and HSA). Results obtained from docking experiments show that the preferred binding site would be in domain IB, which agrees with experimental binding studies.

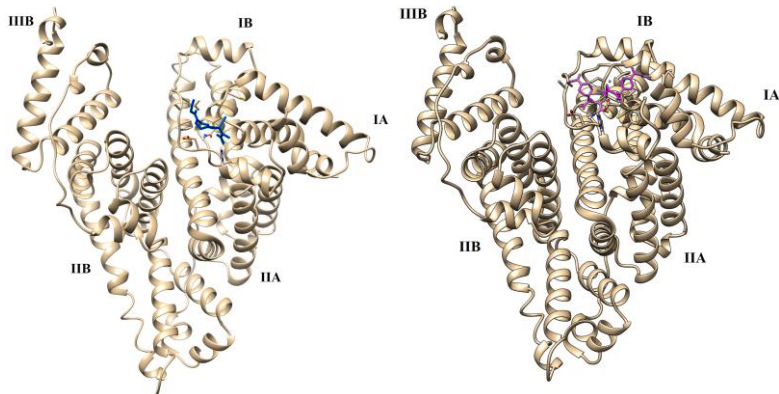


Figure 3. Interactions between L and HSA (left) and PdL and HSA (right).

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CONCLUSIONS

This study investigated the interactions of a thioamide-type ligand L and its Pd(II) complex PdL with human serum albumin (HSA) using fluorescence spectroscopy and molecular docking. Experimental results demonstrated that both compounds bind to HSA with moderate affinity (K_b in the range of 10^2 – 10^4 M⁻¹), with subdomain IB identified as the preferred binding site, as confirmed by competitive binding experiments with specific site markers. Molecular docking further supported that the PdL complex exhibits a somewhat stronger affinity for HSA compared to the free ligand, with binding energy values indicating a more stable interaction at subdomain IB. These findings contribute to a better understanding of the interaction mechanisms between metal-organic compounds and plasma proteins and may be valuable for the further development of metal-based therapeutics with improved pharmacokinetic properties.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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THIN-FILM SUSTAINABLE TECHNOLOGIES: THE POTENTIAL OF VANADIUM OXIDES

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ABSTRACT

Vanadium oxides (VO_x) represent a diverse family of transition metal oxides with rich structural and electronic properties, making them promising candidates for a wide range of applications in sustainable technologies. Their ability to exhibit multiple oxidation states and reversible redox behavior enables their use in electrochemical systems such as supercapacitors, lithium-ion batteries, and electrochromic devices. Simultaneously, VO_x compounds possess tunable optical and semiconductor properties that make them attractive for photochemical applications, including photocatalytic degradation of pollutants and solar-driven water splitting. This mini review explores the multifunctional nature of VO_x materials, with a focus on their integration into thin films and nanostructures that enhance performance and enable scalable use. Emphasis is placed on recent advances in deposition techniques, structure–property relationships, and the dual electrochemical and photochemical potential of VO_x -based systems. By showcasing their adaptability and relevance to clean energy and environmental technologies, this review positions vanadium oxides as key materials for future innovation in green and smart devices.

Keywords: vanadium, oxides, electrochemistry photochemistry.

INTRODUCTION

The growing global demand for clean energy, environmental remediation, and sustainable technologies is driving the development of advanced functional materials. As the world transitions toward low-carbon and circular economies, the design and deployment of materials that are both high-performing and environmentally benign have become critical. In this context, multifunctional thin films of metal oxides have attracted increasing interest due to their wide range of applications, including microelectronic devices, catalysis, biocompatible materials, and solar energy systems (Pacchioni, 2012). Among various candidates, vanadium oxides have emerged as a promising class of multifunctional materials due to their unique physicochemical properties, including a wide range of accessible oxidation states, structural diversity, and strong redox activity. As a result, there has been accelerated research and development of VO_x compounds for a variety of applications, including batteries, energy-saving smart windows, sensors, catalysts, and optoelectronic devices. Tailoring the electronic properties of vanadium oxides has become a key focus in the design of high-performance materials. This is because the electronic, catalytic, and photocatalytic properties of VO_x are highly structure-dependent, and their crystal structure also plays a critical role in determining the material's stability and suitability for specific applications (Hu et al., 2023).

Given their multifunctionality, tunable structure, and compatibility with low-temperature processing, vanadium oxides and their thin-film forms are gaining increasing attention for integration into a wide range of technologies. VO_x thin films, in particular, offer advantages such as controllable thickness, high surface-to-volume ratio, and the ability to be deposited on flexible or microstructured substrates (Dong et al., 2021). These properties make them especially attractive for miniaturized energy storage devices, transparent electronics, electrochromic smart windows, sensors, and photocatalytic coatings. Moreover, various synthesis methods — including reactive sputtering, sol–gel deposition, atomic layer deposition, and thermal evaporation — allow for

precise control over stoichiometry, crystallinity, and morphology, which are critical for optimizing performance in target applications.

In the following sections, this paper presents a concise overview of recent literature on vanadium oxide materials for key applications in electrochemical energy storage, electrocatalysis, and photocatalysis, with a special emphasis on thin-film systems where such studies are available. The aim is to highlight the latest trends, underlying mechanisms, and technological relevance of VO_x -based materials while identifying opportunities and challenges for their future development in sustainable technologies.

STRUCTURAL AND ELECTRONIC PROPERTIES OF VO_x COMPOUNDS

VO_x exhibit a wide range of crystal structures and oxidation states, owing to the ability of vanadium to exist in multiple valence forms—primarily V^{3+} , V^{4+} , and V^{5+} . This allows for the formation of various stoichiometries such as V_2O_3 , VO_2 , V_2O_5 , and V_6O_{13} , each with distinct structural, electronic, and optical properties that directly impact their electrochemical and photocatalytic performance (Alasmari et al., 2025). Mixed-valence VO_x compounds often arise from the introduction of oxygen vacancies. When vacancy concentrations exceed a critical level, they align along crystallographic planes to form shear structures, leading to reorganization of the V–O framework. This process results in structurally related phases, including the Magnéli series ($\text{V}_n\text{O}_{2n-1}$) and Wadsley phases ($\text{V}_{2n}\text{O}_{5n-2}$) (Beke, 2011). From a chemical perspective, vanadium oxide stands out as an excellent catalyst due to its rich and diverse chemistry, which stems from two key factors: the ability of vanadium to adopt oxidation states from +2 to +5, and the variability in oxygen coordination geometries. This structural complexity leads to the presence of differently coordinated oxygen species, which are critical in tuning surface-related physical and chemical properties. Moreover, V_2O_5 has layered crystal structure that enables facile intercalation of ions, making it highly promising for energy storage applications, especially in systems requiring high ionic capacity and reversible redox activity (McNulty et al., 2014). Due to the strong coupling between optical and electrical properties, VO_x materials are particularly attractive in thin-film form for integration into microelectronic devices. Notably, V_2O_5 has also been investigated for use in variable-transmittance electrochromic windows, enabling dynamic control of solar light transmission (Yang et al., 2023). Studies by Wu et al. (Wu et al., 2013) have shown that the electronic properties of VO_x compounds, such as charge carrier concentration, conductivity, and metal-insulator transition (MIT) behavior, are strongly influenced by their microstructure and electron-electron correlations. Controlling these features at the atomic scale has enabled the development of VO_x -based devices for energy storage, conversion, and utilization including lithium-ion batteries, supercapacitors and thermoelectric generators. In particular, VO_2 is well known for having a sharp and reversible MIT, accompanied by significant changes in optical transparency, electrical resistivity, and magnetic susceptibility. These properties open pathways for optoelectronic, thermal, and magnetic applications (Li et al., 2023).

Overall, the remarkable structural diversity and tunable electronic characteristics of vanadium oxides make them a unique class of materials with multifunctional potential. The interplay between oxidation state, crystal structure, and microstructural features governs their electrochemical, optical, and catalytic performance, enabling application-specific optimization. In particular, the reversible redox behavior, high ionic mobility, and metal–insulator transition properties underscore their suitability for a broad spectrum of energy-related technologies. Building on this fundamental understanding, the following sections will explore how these intrinsic properties are harnessed in practical applications, with an emphasis on VO_x -based thin films and nanostructures designed for electrochemical energy storage and photocatalytic systems.

VO_x FOR ELECTROCHEMICAL ENERGY STORAGE

VO_x have gained increasing attention for electrochemical energy storage due to their rich redox chemistry, structural versatility, and ability to reversibly host a variety of ions. Energy storage devices are generally categorized as batteries or supercapacitors, based on their charge storage mechanisms. While batteries offer high energy density, supercapacitors provide much

higher power density but lower energy storage capacity. Traditionally, supercapacitor electrodes are composed of porous carbon materials; however, the incorporation of transition metal oxides has introduced pseudocapacitive behavior - charge storage via fast, reversible redox reactions. VO_x materials exhibit such pseudocapacitive characteristics, either through surface redox reactions or intercalation-driven processes, leading to significantly enhanced energy density. In thin-film form, VO_x also offers advantages in terms of tunable morphology, integration into microscale systems, and improved electrochemical performance. The following section reviews recent advances in the application of specific VO_x compounds in supercapacitors and batteries, highlighting their structure–function relationships and electrochemical behavior.

Karthikeyan et al. (Karthikeyan et al., 2025) demonstrated that 2D VO_x nanosheets, synthesized hydrothermally, show promising supercapacitor performance with high specific capacitance, excellent cycling stability, and a high-power density in an asymmetric configuration - highlighting their potential for advanced energy storage applications. However, VO_x materials often face challenges that limit their ability to reach theoretical capacities or display full multifunctional behavior, such as voltage-dependent color changes. These limitations are primarily due to their inherently low electrical conductivity and structural instability during charge–discharge cycling, which can lead to structural collapse. To overcome these issues and fully exploit their potential, recent strategies have focused on heteroatom doping and combining VO_x with more conductive materials to enhance overall conductivity. For example, nitrogen-doped V_2O_5 on CoS (Zhou et al. 2025) and sulfur-doped V_xO_y on carbon supports (Song et al., 2025) have shown significant improvements in both energy and power densities. Moreover, the combination of VO_x pseudocapacitive properties with its electrochromic behavior has led to the development of multifunctional electrochromic supercapacitors. Yang et al. (Yang et al., 2024) developed copper vanadium oxide yolk–shell microspheres where adding Cu as rigid component weaken structural collapses and to improve conductivity. Such electrode material displays three color transitions at potential 1.2 V, 0 V and -0.8 V.

In thin-film form, V_2O_5 has been deposited using RF magnetron sputtering and investigated for its potential application as a supercapacitor electrode and as a cathode material for Li-ion batteries. Studies have shown that key deposition parameters (oxygen partial pressure, sputtering power, substrate temperature, and deposition time) influence the microstructure, crystallinity, and oxidation state of the resulting films. These microstructural characteristics, in turn, affect the electrochemical behavior of the films, including their capacitance, cycling stability, and Li^+ intercalation capacity (Dhananjaya et al., 2020).

In terms of battery applications, VO_x materials have been widely explored as cathodes for Li-ion batteries; however, recent research has increasingly focused on their use in zinc-ion batteries (ZIBs). In particular, thin films of V_6O_{13} have been deposited via DC magnetron sputtering, demonstrating promising performance (Zhao et al., 2025). The unique layered structure of V_6O_{13} facilitates efficient electrolyte penetration, while the V–O interlayers promote reversible Zn^{2+} ion insertion and extraction. Furthermore, these thin-film electrodes exhibit excellent structural stability during cycling, a critical factor in extending the operational lifespan of energy storage devices. Also vanadium oxide nanostructures showed potential in using as cathode for K-ion batteries (Xie et al., 2025), Na-ion batteries (Sayeed et al., 2025), ammonium-ion batteries (Zhang et al., 2025), and Li-S batteries (Hou et al., 2025).

To conclude, recent progress in engineering the VO_x materials highlights their significant potential for advanced electrochemical energy storage. These developments reflect a growing ability to tailor their performance through controlled synthesis and device integration. Looking ahead, further research into enhancing conductivity, stability, and multifunctionality will be key to unlocking the full capabilities of VO_x in next-generation energy storage systems.

VO_x FOR ELECTROCATALYSIS AND PHOTOELECTROCATALYSIS

Recent research has expanded the application of VO_x into electrocatalysis and photoelectrocatalysis, where they demonstrate activity in energy conversion reactions. Their catalytic behavior is strongly influenced by their oxidation state, defect chemistry, and interaction

with light or external potentials. In photoelectrocatalysis, VO_x materials are particularly attractive due to their ability to absorb visible light and facilitate charge transfer at the interface. This section presents recent advances in VO_x -based catalysts, with an emphasis on structural tuning, combinations with other materials, and performance metrics in both electrochemical and light-assisted catalytic processes.

To demonstrate that the oxidation state and crystal structure of vanadium in VO_x play a significant role in electrocatalytic activity, Choi (Choi, 2022) compared differently synthesized VO_x materials for the oxygen evolution reaction (OER) and found that monoclinic VO_2 exhibits the highest catalytic activity. Another promising application of VO_x materials in electrocatalyst design is their use as a support for nanoparticles. Recent studies showed that single-atom Co dispersed onto highly crystalline V_2O_5 exhibits high OER activity and excellent durability (Youn et al., 2022), which is crucial for potential real-world applications. Additionally, combining oxygen-deficient VO_x materials with carbon to form supports for Ir nanoparticles has shown high activity for the hydrogen evolution reaction (Zhan et al., 2024).

Due to their relatively narrow bandgap, VO_x materials can efficiently absorb visible light, making them suitable for photoelectrocatalytic applications where electron excitation from the valence to the conduction band is essential. Ko et al. (Ko et al., 2022) developed a facile method to deposit oxygen-deficient VO_x nanosheets and demonstrated that a higher content of oxygen vacancies improved charge transport and interfacial charge transfer, enhancing the photoelectrocatalytic oxidation of water and methanol. However, a major limitation of VO_x photoanodes is their high electron-hole recombination rate, which reduces photocatalytic efficiency. One effective strategy to overcome this involves combining VO_x with other materials, such as noble metal nanoparticles. For instance, Ag nanoparticles have been shown to enhance photocatalytic performance by suppressing charge-carrier recombination at the metal/semiconductor interface (Waheed et al., 2025).

Overall, VO_x materials show great promise as electrocatalysts and photoelectrocatalysts, with their performance tunable through structural engineering, defect control, and strategic integration with other materials.

VO_x FOR PHOTOCATALYSIS AND ENVIRONMENTAL APPLICATIONS

VO_x materials have gained significant interest in photocatalysis and environmental remediation due to their tunable bandgap, ability to generate reactive oxygen species under illumination, and structural versatility that supports surface modification. In environmental applications, VO_x -based photocatalysts have been widely studied for the degradation of organic pollutants, particularly dyes, under visible-light irradiation. Recent strategies to improve VO_x performance have focused on overcoming its limitations by enhancing charge separation and increasing stability, often through doping and composite formation to stabilize surface-active sites. This section discusses recent advances in VO_x -based nanostructures and composite materials for dye degradation, with an emphasis on the role of structural modifications in improving photocatalytic performance.

To demonstrate the potential of VO_x nanoparticles as photocatalysts for Methylene Blue (MB) dye degradation, Nhan et al. (Nhan et al., 2024) employed a hydrothermal synthesis followed by annealing, showing that the annealing temperature strongly influences the morphology, crystal structure, optical properties, and consequently, the photocatalytic activity of VO_x . An improvement in the photocatalytic activity of V_2O_5 has been observed through Zr doping, which enhances the rate constant of the Rhodamine B (RdB) dye degradation reaction (Haribaaskar & Yoganand, 2024).

Another approach to enhance the photocatalytic efficiency of VO_x materials involves forming composites with complementary materials that impart desirable properties. For example, a type-II heterojunction between MoS_2 and V_2O_5 was synthesized to facilitate the photodegradation of MB. This heterostructure material demonstrated significantly higher MB removal efficiency under UV light compared to individual MoS_2 or V_2O_5 photocatalysts, highlighting its promise for wastewater treatment applications (Nadeem et al., 2025). Combining VO_x with graphitic carbon nitride (g-

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C₃N₄) has proven highly effective not only for Rhodamine B (RhB) dye degradation but also for enhancing photocatalytic hydrogen (H₂) production. The favorable band alignment between V₂O₅ and g-C₃N₄ promotes the formation of a heterojunction, which facilitates efficient charge separation and suppresses electron-hole recombination, ultimately resulting in enhanced photocatalytic activity (Zhao et al., 2020).

CONCLUSIONS

In this work, we have presented recent advances in the use of VO_x as a versatile class of materials positioned at the intersection of electrochemistry, photochemistry, and materials science. Their rich structural diversity, wide range of oxidation states, and tunable electronic and optical properties have enabled integration into various sustainable technologies, including energy storage devices, electrocatalysts, and photocatalysts. In thin-film and nanostructured forms, VO_x compounds offer unique advantages such as enhanced surface area, improved charge transport, and compatibility with flexible and miniaturized devices.

This review has highlighted recent progress in the synthesis, structural control, and functional optimization of VO_x materials, with particular emphasis on their dual electrochemical and photochemical potential. Despite notable advancements, challenges remain, such as limited electrical conductivity, structural instability during cycling, and charge recombination in photocatalysis. Overcoming these issues through strategic material design includes doping, heterostructuring, and defect engineering will be essential to unlocking the full potential of VO_x in future applications.

Continued interdisciplinary research into the structure-property-performance relationships of vanadium oxides will not only deepen fundamental understanding but also accelerate their implementation in next-generation clean energy and environmental technologies.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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ARTIFICIAL INTELLIGENCE SUPPORTED APPLICATION FOR EXPLOSIVE CLADDING PROCESS SPECIFICATION

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ABSTRACT

Explosive cladding is becoming increasingly widespread in the field of metalworking technologies. The advantage of this technology is that it cannot be combined with other welding technologies, and dissimilar metals can be joined by cohesion joint. The wide range of materials and the different properties of metallic materials (modulus of elasticity, tensile strength, hardness, ductility, etc.) are the reasons for the difficulty of determining the welding process specification. In addition, many explosives (with blast velocities below the speed of sound) are suitable for creating the appropriate bond strength. AI is a good tool for several applications and process parameter calculations. The innovative application supported by AI can help the welding engineer in the explosive welding process parameter determinations. For the welding process, the engineer chooses suitable metal and explosive materials. AI, based on the explosive material parameters and the metallic materials' mechanical properties, calculate the explosive welding setup parameters. In this article, the algorithm of the application and the theoretical and practical elements of the technological design are presented in detail. The developed application facilitates the technological design of the otherwise complex blast welding process.

Keywords: welding, AI, application, explosive cladding, algorithm.

INTRODUCTION

Welding is a widely used industrial application worldwide. Welding is a joining technology that establishes a cohesive bond. In the industrial area, it uses fusion and solid-state welding processes. The welding specification always depends on the materials and structures. For fusion welding processes, high-temperature heat is required because bonding is created by melting the materials. Fusion welding is practical for metals and specific polymers. Because of the wide variety of materials, fusion welding can't be applied in all cases. Solid-state welding is another group of welding processes, where bonding between materials is created without melting or partial melting of the components.

Solid-state welding processes, e.g., resistance spot welding, ultrasonic welding, and explosive welding. The process specification in the case of the solid-state welding processes is also a complex process. It needs to take into account the process, and firstly, the chemical, physical, and mechanical properties of the weldable materials. The second aspect in the case of the process selection is the product structure (thickness of the walls, design of the structure, etc.). Solid-state welding process means that the components are connected by force and sometimes with heat, but without melting. The bonding between atoms is achieved by bringing the atoms of the two components within the bonding distance with force.

Explosive welding is a specialised welding process among solid-state welding processes (Pocalyko, 1964; Holtzman, Cowan, 1965; Pocalyko, 1981). In this process it needs to take account the possibilities and the limits of the process and the welded materials. In the literature, one can find examples only for metallic materials. The most common process for bonding metal sheets or plates (Findik, 2011; ASM Handbook 1992; Mousavi, Al-Hassani, 2005; Marc, et. al. 1980). It is possible to create butt welding by the explosive welding process, but in industrial

applications, this is not feasible. The explosive welding process is useful for bonding large sheets and plates. For the explosive welding process, the energy to bond the materials came from the established gas pressure of the explosion (Zhang, Zhang, Feng, 2012; Liu, Zhang, Yang, 2011; Peters, 2005; Zhang, et. al., 2011). The wide range and different properties of explosives complicate the process specification. The process specification needs several calculations based on the weldable materials, structural properties, and explosive materials properties. To earn suitable parameters, it requires knowledge of the material properties and the calculation of the explosion welding process setup parameters (Havlicek, Havlicek, 2012; Meyers, Murr, 1980; Davis, 2002; Staudhammer, et. al., 1981; Zhang, 2008; Kovács-Coskun, 2016). It can be seen that the explosive welding process appears simple, but it requires calculation based on a large amount of data (Kugyela, et. al. 2025; Lukács, et. al. 2012; Hirsch, 1995; Catovic, 2020). The AI can be a valuable aid in achieving suitable results.

In recent years, significant changes have occurred in the approach to complex engineering problems (Kamaruzaman, et. al., 2017). The increasing volume of data (Quick, et. al., 2014), the number of variables to be managed (Sadeghi-Bazargani, et. al., 2011), and the need for precise adjustment have all contributed to a shift in how design processes (Grønbaek, et. al., 2017) are carried out. Calculations have become more demanding, and greater emphasis is now placed on finding effective methods to handle (Greenhalgh, et. al., 2005) them reliably and efficiently. Machine learning (Zhou, 2021) and intelligent software (Perkusich, 2020) are not there to think for us, but to take the monotonous, time-consuming work (Rios, 2020) off our shoulders and help us find the best solutions (Standley, 2010). This study presents three areas where artificial intelligence (AI) can help engineers (Patange, et. al., 2023): computing, database management, and application development (Wasserman, 2010) in the preparation of the explosive welding process (Greenberg, 2019). As every engineer knows, one of the most difficult parts of design is balancing all the different considerations: strong enough but not too expensive, lightweight but durable. In the past, this required many iterations, many experiments, and a lot of time. AI is a great help here because it can quickly run through thousands of variants and analyze them to find the best solutions. It is also useful for simulations (Jeon, et. al., 2016), such as choosing explosives or studying gap sizes, because it shortens calculation time while still providing accurate results. Another challenge in engineering is reviewing and managing huge amounts of data. Every project generates a lot of measurements, experience, and documentation (Alwazae, et. al., 2014). This is where AI comes in handy: it can connect data, recognize patterns, and even predict problems. For example, in explosive welding processes, AI uses machine data to indicate when the choice of explosive material is inappropriate or to recommend changes to the size of the gap. This not only saves time and money, but also improves quality. Nowadays, almost everyone has a smartphone, and engineers are no exception. More and more applications are being developed to facilitate engineering work (Ejiwale, 2014). Many of them already have built-in artificial intelligence: for example, they provide real-time bug fixes, optimization suggestions, or help solve more complex problems. The advantage of AI-compatible applications is that they are not only affordable for large companies, but also accessible to smaller offices and individual designers (Javaid, et. al., 2022). AI does not replace engineers, but helps them make better decisions and work faster. It makes it easier to navigate data and provides advanced tools that were previously unimaginable. When used effectively, AI does not detract from the profession but enhances it: it makes design more accurate, efficient, and enjoyable.

AI is a valuable tool for data analysis, which supports the calculation of welding process parameters; however, it requires a welding expert to determine the final parameters.

MATERIAL AND METHODS OF WORK

In this research, we aimed to develop an AI-supported application that assists in specifying the explosive welding process. We focused on the use of metallic sheet or plate materials for explosive welding. This process is specifically referred to as cladding. Explosive cladding is a solid-state process in which controlled explosive detonations force two or more metals together at high pressures, resulting in a high-quality metallurgical bond between the colliding surfaces

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(Holtzman, 1965; Pocalyko, 1981; Findik, 2011; ASM Handbook 1992; Mousavi, Al-Hassani, 2005).

Explosive Cladding

Figure 1 below shows the parallel setup of the explosion welding process, and Figure 2 shows the cross section of the explosive welded joint. The wave of the explosion pressure causes a special joint formation, which can be seen in the cross-section of the joint.

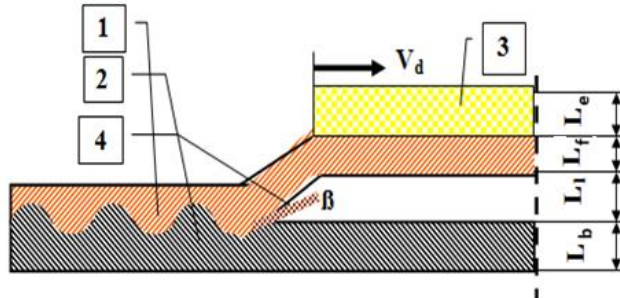


Figure 1. Setup of the explosion welding (1-clad plate, 2-base plate, 3-high explosive, 4-jet).

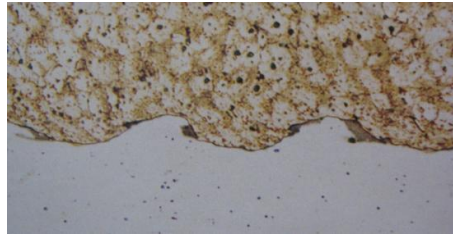


Figure 2. Cross-section of the explosive welded bond.

It is used for determining the setup parameters and the properties of the explosive material, as well as the properties of weldable metals, including material parameters and geometrical parameters (Kugyela, et. al., 2025). The calculation is suitable only for the parallel welding setup.

Based on the welding setup (Figure 1), it can be observed that the key process parameters are the gap size L_l and the thickness of the explosive material L_e . During the selection of explosive materials, it is necessary to consider a critical limit related to the detonation velocity of the explosive material. The sound velocity in the material needs to be smaller than the speed of the flyer sheet's collision v_c with the base plate (Kugyela, et. al., 2025; Lukács, et. al. 2012). Based on the literature data, the gap size L_l of the welding setup needs to be between the following range (Pocalyko, 1964; Hirsch, 2012; Catovic, 2020), where L_f is the thickness of the flyer plate:

$$0,5 \cdot L_f < L_l < 1,6 \cdot L_f \quad (1)$$

To determine the gap size of the welding setup, the following equation (2) can be found in the literature (Kugyela, et. al., 2025):

$$L_e = (\rho_f \cdot L_f) / \rho_e \quad (2)$$

where:

L_e – thickness of the explosive material (cm)

ρ_f – density of the flyer plate (g/cm^3)

L_f – thickness of the flyer plate (cm)

ρ_e – density of the explosive material (g/cm^3)

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The key setup parameters are determined by the introduced method. Data on the selected explosive material and the flyer plate material properties are available from an internet database with AI assistance.

Artificial intelligence in flowchart design

A well-thought-out flowchart has always been a cornerstone of technology design (Whitfield, et. al., 2011). In industry and engineering practice, flowcharts have been used for decades to capture the steps of a system or production line in a clear and logical way. Such a diagram is not just a drawing, but a tool that facilitates communication between team members (Hedman, 2015), helps to identify errors and provides a basis for detailed calculations.

In recent years, engineers have come up with new tools that incorporate artificial intelligence (Pival, 2023). These systems can make predictions, suggest parameters, and often automatically produce sketches. While these tools are undoubtedly useful, it is important to understand that they can only be used effectively and safely with proper expert supervision and continuous monitoring.

Calculations and parameter setting

One of the most time-consuming parts of process design is parameter setting (Rios, et. al., 2020). When designing industrial processes, such as welding processes, a balance (Weman, 2011) must be found between dozens of input and output requirements: material thickness, material quality, explosive material, gap size, and costs. Calculating these manually, especially when there are many variables, requires significant resources.

Artificial intelligence can be of considerable help at this stage. The software can run hundreds or even thousands of combinations at once and recommend the parameter sets that best suit the specified objectives. In explosive welding, an AI-based tool (Goka, et. al., 2024) can predict the appropriate explosive material for different material qualities and thicknesses, its quantity, and the gap parameters, and then rank the options.

However, these results can only serve as a starting point. The engineer must make the final decision on which solution can be implemented based on practical experience and on-site conditions.

Flowchart generation

Automatic flowchart creation is a new feature of modern design software. The engineer enters the basic objectives into the system, such as the data of the materials to be welded and the explosive to be used, and the system creates a preliminary flowchart in logical order based on this information. This diagram includes the relationships between each step and the main elements. This approach proves especially helpful during the initial phase of planning, as it can reduce preparation time and make it easier to examine several alternatives. Even so, each proposal must be reviewed by someone with practical experience, since certain configurations may not meet regulatory requirements or may lead to unnecessary costs.

The role of peer review

Peer review is a key element in the design process. Artificial intelligence does not replace engineering experience and knowledge, but complements it. AI works only on the basis of inputs and algorithms and does not see the full context or perceive practical problems.

Therefore, all AI-generated flowcharts (Arbaz, et. al., 2024), calculations and proposals need to be manually reviewed, checked for reality and appropriateness of the results. In many places, it is good practice for plans to be reviewed jointly by several experts, who also provide feedback on each step to the system so that it can produce more accurate results in the future.

Peer feedback, therefore, not only improves the quality of the plan, but is also essential for 'teaching' the system. Continuous refinement and feedback

A well-designed process is not a single iteration. As you work, new information, objectives, and external circumstances may change. These changes need to be incorporated into the plans, and the calculations need to be re-run.

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The advantage of AI-based systems is that they can react quickly to changes and generate new proposals immediately. However, each refinement has to be followed by a new peer review and feedback.

This “circular” design process ensures that the final design is both economically and technologically optimal and feasible.

Artificial Intelligence in the Process Specification

AI assists in finding the parameters of the explosive and fire plate material for the setup parameter determination. AI rapidly finds the data and uses it for calculations. The material selection is interactive because the user must select materials based on the work's goal. AI can suggest solutions, but the final decision needs to be made by the user. Material selection is limited by the rules described above. The parameter limits are included in the application program. AI assists in determining the parameters, and the algorithm of the application is illustrated in Figure 3.

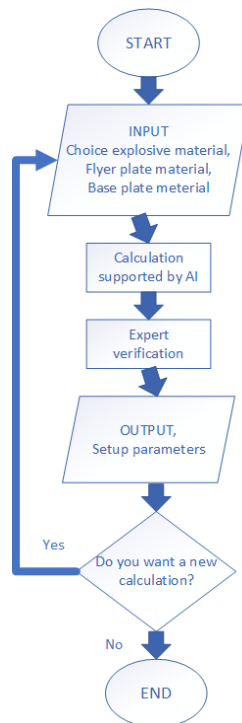


Figure 3. The AI-assisted application algorithm.

Users need to control both the earned results and the AI-suggested results continuously.

CONCLUSIONS

The explosive cladding process is a specialised metal bonding technique that offers several advantages over conventional joining methods. One of its most significant benefits is the ability to create a strong bond between metals that are typically incompatible, such as aluminium and steel. Another notable advantage is that there are practically no limitations regarding the thickness ratio of the metals to be joined, making the process highly versatile for various geometries. Additionally, the method requires only minimal equipment and tooling, making it a cost-effective alternative to traditional welding processes.

Explosive cladding finds applications in several industrial sectors, particularly where special multi-component materials are required. The electrical industry, vehicle manufacturing, and nuclear technology widely utilise this process to produce bi- or multilayered plates, sheets, wires,

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and other components. Typical applications include bimetallic contact elements in electrical equipment, contacting elements for power transformers, and bonding of superconductors.

Blast welding is a versatile and widely used process in the industry. Unfortunately, in industrial practice, most engineers lack adequate knowledge of explosive welding. The presented application will assist engineers who lack a broad understanding of explosives and blasting specialists who are familiar with explosives but not with welding technology in their technological planning.

The app is a help for engineers, but the responsibility for the technology's suitability lies with the welding technologist. In practice, even with the specified parameters, blast welding should only be carried out under the supervision and with the support of a blasting technician for security reasons.

The introduced AI supported process parameter determination process algorithm shown in Figure 3, which can demonstrate that Artificial intelligence is nowadays an undoubtedly useful tool in technology parameter determination as well in the case on the explosive welding process. It helps engineers to manage data, perform calculations quickly and determine optimal parameters. It makes design work faster, more transparent and more efficient.

At the same time, AI can only be used safely and effectively if designs are accompanied by continuous peer review and feedback. Without engineering knowledge, practical experience and consideration of local specificities, AI proposals alone are not sufficient.

However, if used well and integrated into the design process with appropriate control, AI can become a truly valuable tool for modern engineering practice.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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SURFACE MODIFICATION TECHNIQUES FOR DENTAL IMPLANTS

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ABSTRACT

Surface finishing of dental materials significantly influence their functional properties, biological compatibility, and long-term clinical performance. Given the diversity of materials used, including ceramics, metals, polymers, and bioactive composites—each material type necessitates a tailored approach to surface layer modification. This review focuses on the classification and analysis of primary surface finishing methodologies applied to dental materials. Mechanical techniques aimed at increasing micro-roughness are described alongside chemical methods targeting surface property alteration. Physical processes such as plasma activation and laser texturing are also examined. Attention is dedicated to treatments enhancing surface bioactivity, including the deposition of bioactive coatings and chemical surface functionalization. The study emphasizes the correlation between applied surface modification techniques, resultant changes in surface topography, and biological responses within the oral environment. Moreover, the necessity of customizing technological approaches based on specific clinical requirements is underscored. The insights gained provide guidance for the optimal selection of surface finishing according to material type and intended clinical application

Keywords: surface finishing, modification, techniques, dental implant.

INTRODUCTION

Dental implants represent one of the most significant advancements in modern dentistry, enabling the restoration of function and aesthetics in patients with tooth loss. The success of implantation, however, depends not only on surgical performance and proper system selection but also—critically—on the implant's ability to achieve stable and long-term integration with bone, known as osseointegration. This ability is strongly influenced by the implant surface properties, which result from specific surface treatments. Research in implantology over the past decades has demonstrated that surface topography, chemical composition, and structure significantly affect cellular behavior in direct contact with the implant, thereby determining the quality and speed of osseointegration (Albrektsson et al., 1981; Gittens et al., 2014; Wennerberg & Albrektsson, 2009). While earlier implants featured smooth, machined surfaces, current trends focus on active and biofunctional surfaces that not only passively support bone growth but also actively stimulate cellular adhesion, proliferation, and differentiation (Rupp et al., 2006).

The aim of this review article is to analyze existing dental implant surface treatment techniques in detail, explain their principles, advantages, and limitations, and connect them to clinical application. Special attention is given to the relationship between surface modification and biological response in the peri-implant environment.

CLASSIFICATION AND PRINCIPLES OF SURFACE MODIFICATIONS

Dental implant surface treatment techniques can be classified based on their mechanism of action into four main categories: mechanical, chemical, physical, and bioactive (biological) modifications. Each of these categories affects the implant surface in a specific manner, modifying its topography, chemical composition, and biological cell response. The primary goals of these

treatments are to enhance osseointegration, accelerate healing, and ensure the long-term functionality of the implant.

Mechanical Modifications

Mechanical techniques are based on the physical modification of the surface using abrasive or etching procedures. The most common methods include sandblasting with aluminum oxide or titanium oxide particles, which increase surface microroughness and improve mechanical anchorage of cells. Combining this with acid etching (e.g., HCl, H₂SO₄)—known as SLA (Sandblasted, Large grit, Acid-etched) treatment—results in a dual-level topography that positively influences osteoconductivity.

The advantages of these techniques include their simplicity and well-established clinical performance; however, potential disadvantages include residual abrasive particles or surface heterogeneity (Buser, et al., 2004).

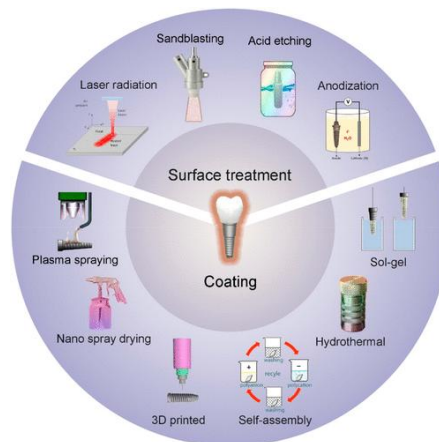


Figure 1. Surface Modifications of Implants (Lu et al., 2023).

Chemical Modifications

These modifications alter the chemical composition or reactivity of the surface through chemical reactions, oxidation, or anodization. For instance, alkaline treatment of titanium with sodium hydroxide creates a surface layer rich in hydroxyl groups, which supports apatite formation in simulated body fluids (SBF). Anodization produces a porous titanium oxide layer of varying thickness and charge, enhancing its ability to bind Ca²⁺ and PO₄³⁻ ions. These chemical modifications are particularly significant for promoting osteoinduction and can be combined with additional functional groups (e.g., carboxyl, amino) (Kokubo, & Takadama, 2006).

Physical Modifications

Physical techniques modify the surface using physical forces, often without direct material contact. Plasma treatment utilizes ionized gas to remove organic contaminants and increase surface hydrophilicity. This improves protein and cell adhesion, accelerating the onset of osseointegration. Laser texturing allows precise creation of microstructures that guide cell growth and vascularization at the implantation site. These techniques provide a high degree of control over surface topography without compromising the structural integrity of the implant (Sul, et al., 2002; Scarano, et al., 2003).

Bioactive and Biological Modifications

Bioactive modifications go beyond physico-chemical changes and involve the application of materials that actively stimulate biological responses. These include hydroxyapatite coatings, bioactive glasses, collagen layers, peptides (e.g., RGD sequences), growth factors (e.g., BMP-2),

or antimicrobial agents (e.g., chlorhexidine, silver). Such layers can be applied via methods like sol-gel processing, electrophoretic deposition, or chemical bonding. The goal is not only to enhance cell adhesion but also to direct cell differentiation and suppress inflammatory responses (Canullo, et al., 2017; Hench, 2006).

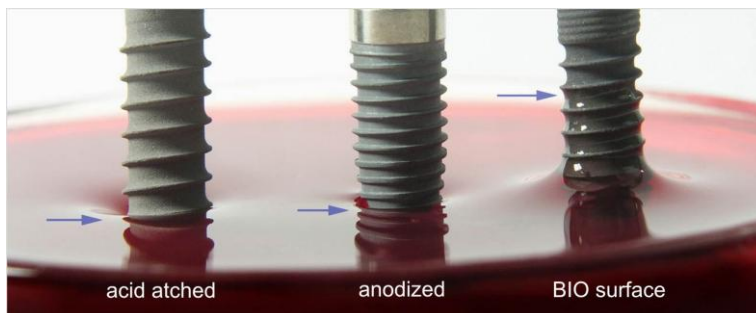


Figure 2. Comparison of liquid contact with implant surfaces: etched, anodized, and bioactive. (Dental Surgery Channel, 2019).

MECHANICAL MODIFICATIONS: MICRO- AND MACRO-TEXTURING

Mechanical surface modifications represent one of the oldest and most widely used approaches in dental implant surface engineering. Their primary goal is to enhance the topographic complexity of the surface, thereby improving its mechanical and biological properties, especially during the early phases of osseointegration. Micro- and macro-texturing increase the overall contact area between the implant and bone, which leads to better load distribution, enhanced fibrin network adhesion, and stimulation of osteoblastic activity.

Micro-Texturing

Micro-texturing focuses on creating microscopic surface irregularities ranging from a few micrometers to several tens of micrometers. These microstructures support cell adhesion, proliferation, and extracellular matrix organization. The most commonly used micro-texturing techniques include:

- Sandblasting: This technique involves treating the implant surface with a high-pressure stream of abrasive particles (e.g., aluminum oxide, titanium oxide). It produces stochastic surface roughness and increases surface energy, promoting better osteoblast attachment (Wennerberg, & Albrektsson, 2010).
- Acid-etching: The use of strong acids (e.g., HCl, H₂SO₄, HF) causes selective corrosion of the titanium surface. This process creates pits and microcracks that enhance cell adhesion and improve the biological response (Buser, et al., 1991).
- Combined Techniques – SLA (Sandblasted, Large Grit, Acid-Etched): This technique combines coarse-grit sandblasting with subsequent acid-etching, resulting in the so-called SLA surface. It has become the gold standard in commercial titanium implants. SLA surfaces demonstrate high osteoconductivity, faster osseointegration, and favorable clinical outcomes (Schüpbach, et al., 2005).

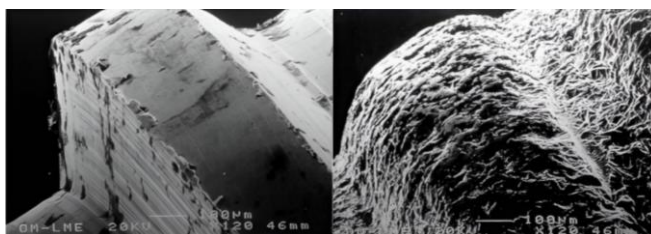


Figure 3. Implant surface before and after sandblasting (Dental Surgery Channel, 2019).

Macro-Texturing

Macro-texturing is performed on the scale of hundreds of micrometers to millimeters and affects the design of the entire implant. It includes features such as thread geometries, grooves, collars, and porous structures that enhance primary stability and enable improved biomechanical anchorage in the bone. Although macro-texture does not have as direct an effect on cellular response as micro-texture, it plays a key role in load transmission and in preventing micromovements that could disrupt the healing process (Mangano, et al., 2015).

Recent advances in 3D printing (additive manufacturing) enable the fabrication of macro-porous titanium structures that mimic the trabecular architecture of natural bone. These implants offer not only excellent mechanical integrity but also provide space for vascular and osteogenic cell ingrowth, thereby promoting so-called vascularized osseointegration (Mangano, et al., 2015).

Synergistic Potential with Other Techniques

Currently, combinations of mechanical techniques with chemical or physical modifications are increasingly used, leading to a synergistic effect. For example, surfaces with micro-roughness created by sandblasting can be further plasma-treated to enhance hydrophilicity or coated with a bioactive layer, resulting in an implant with optimized mechanical and biological performance (Gomez-Florit et al., 2021).

CHEMICAL METHODS: SURFACE REACTIVITY AND BIOACTIVITY

Chemical surface modification methods represent an important group of techniques that allow targeted alteration of the chemical composition and functional groups of the implant surface without significantly changing its macroscopic structure. Their goal is to enhance the bioactivity of the surface, improve its affinity for biological molecules, promote apatite formation, and optimize interaction with host tissue. Unlike purely mechanical techniques, these methods can create chemically active surfaces that act as “biological signals” supporting cell adhesion, proliferation, and differentiation.

Alkaline and Acid Treatments

One of the most widely used chemical methods is alkaline etching of titanium using strong bases, most commonly sodium hydroxide (NaOH). This treatment leads to the formation of a hydrated sodium titanate layer rich in –OH groups. These hydroxyl groups increase surface hydrophilicity and provide a favorable environment for apatite nucleation in simulated body fluid (SBF) (Kokubo, & Takadama, 2006). Similarly, acidic etching solutions (e.g., H₂SO₄, HCl, HF) are also used, producing fine microtubular or pitted surface structures on titanium while simultaneously activating the surface chemically. A combination of these methods (e.g., alkaline-acid treatment) is used to achieve a synergistic effect of roughness and chemical reactivity (Sul, et al., 2002).

Anodic Oxidation

Anodization is an electrochemical method in which a titanium implant is subjected to a controlled oxidation process in a conductive electrolyte under applied voltage. This process produces a porous titanium dioxide (TiO₂) layer whose properties—thickness, porosity, surface charge—can be precisely tuned by modifying the process parameters (voltage, electrolyte type, duration). The porous TiO₂ enhances surface energy, ion exchange capacity, and bioactivity (Macak, et al., 2007; Popat, et al., 2007).

In some cases, anodization can lead to the formation of nanotubular structures that serve as carriers for drug delivery, growth factors, or antimicrobial agents, thereby combining chemical surface modification with a therapeutic function (Nobel Biocare, n.d.).

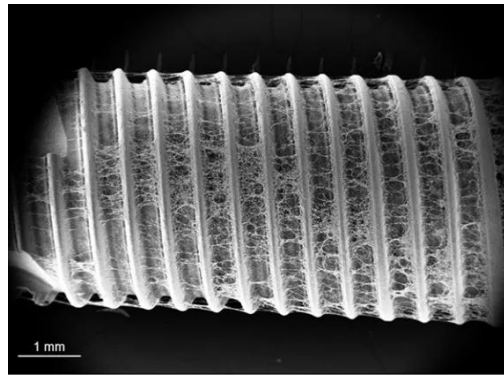


Figure 4. Anodic oxidation of the implant surface (Nobel Biocare, n.d.).

Chemical Deposition of Bioactive Compounds

Another group of techniques involves the direct chemical deposition of bioactive agents onto the implant surface. This includes:

- Deposition of hydroxyapatite (HA) using methods such as sol-gel processing, wet chemical deposition, or electrophoretic techniques. These coatings promote osteoconduction and accelerate the mineralization of the bone matrix.
- Immobilization of bioactive molecules—such as peptides (e.g., RGD sequences), proteins (e.g., fibronectin, vitronectin), or growth factors (e.g., BMP-2, TGF- β)—which are chemically bound to the activated surface via silane bonds, carboxyl, or amino groups. Such surfaces provide specific bioactive cues that stimulate cellular responses and differentiation (Schliephake, et al., 2009).

Chemical Functional Modification

Advanced chemical techniques also include the addition of functional groups or nanomaterials that alter the surface charge, polarity, and reactivity. For instance:

- Surfaces modified with carboxyl (-COOH) or amino (-NH₂) groups improve interactions with extracellular matrix proteins and stimulate osteoblasts (Park & Lakes, 2007).
- Nanocrystalline calcium phosphates applied as surface coatings enhance natural mineralization (Barrère, et al., 2003).

These chemical modifications can also influence the presence and orientation of adsorbed proteins, which is crucial for subsequent cell interaction (e.g., adsorption of fibrinogen, albumin, and vitronectin).

PHYSICAL TECHNIQUES: ENERGY-BASED BIOACTIVATION

Physical techniques for dental implant surface modifications utilize various forms of energy (plasma, laser, UV radiation) to modify surface properties without altering the bulk structure of the material. These methods primarily aim to increase surface energy, alter chemical composition of the surface layer, remove contaminants, improve hydrophilicity, and enhance bioactivity. They are particularly valuable for modifying the surfaces of titanium, ceramics, or polymers without mechanical disruption.

Plasma Treatment

Plasma treatments are among the most widely used physical techniques, exposing the implant surface to low-temperature plasma generated from various gases (e.g., argon, oxygen, nitrogen, ammonia). This process modifies the chemical and electrical properties of the surface through interaction with ionized particles, UV radiation, and electrons.

- O₂ plasma increases the number of –OH groups, significantly enhancing surface hydrophilicity and the adsorption of proteins like fibronectin and albumin (Lee et al., 2005).
- NH₃ plasma induces the formation of –NH₂ groups, which positively influence osteoblastic differentiation and adhesion (Yoshinari, et al., 2002).

Plasma also removes organic contaminants that naturally accumulate on implant surfaces during storage (the so-called "biological aging" effect) (Deligianni et al., 2001). Plasma treatment is advantageous for being safe, fast, and non-invasive, while preserving surface topography—especially important for delicate structures such as nanotubes.

Laser Texturing

Laser techniques use concentrated light beams (e.g., Nd:YAG, CO₂, or femtosecond lasers) to selectively remove or melt surface material, creating precise micro- and nanostructures. These methods enable the fabrication of reproducible surface textures without the need for chemical agents.

- Laser-created micro-roughness (e.g., grooves, pits, waves) supports cell guidance, enhanced adhesion, and improved organization of the extracellular matrix (Anil, et al., 2011).
- Additionally, laser treatment sterilizes the surface and removes manufacturing residues (Yong, et al., 2013).

Some studies show that laser processing may also enhance the osteoinductive properties of titanium implants, especially when combined with chemical coatings (Scarano, et al., 2006). Although technically more demanding, laser methods are attractive for implantology due to their precision, controllability, and absence of secondary contaminants.

UV Photofunctionalization

Ultraviolet (UV) radiation—particularly at a wavelength of 254 nm—can alter the surface energy of titanium implants through photo-induced oxidation and removal of carbon contaminants. This process, known as UV photofunctionalization, converts hydrophobic surfaces into superhydrophilic ones, dramatically improving cell adhesion and accelerating osseointegration (Aita, et al., 2009).

UV treatment restores the “biological youth” of titanium surfaces, which are otherwise passivated over time by carbon adsorption (Ogawa et al., 2010). Experimental models demonstrate that UV-activated titanium integrates into bone 2–3 times faster than non-activated surfaces (Ueno, et al., 2010). UV photofunctionalization is non-thermal, eco-friendly, and easily applicable in clinical settings directly before implantation.

Ion Implantation

Ion implantation involves injecting high-energy ions (e.g., Ca⁺, P⁺, N⁺, Ag⁺) into the implant surface under high voltage. This technique can modify the chemical composition, valence state, surface charge, and biological activity without mechanical damage to the substrate (Huang et al., 2007).

- For example, silver ion (Ag⁺) implantation provides a strong antibacterial effect, making it suitable for peri-implantitis prevention (Gugala, et al., 2014).
- Implantation of calcium or phosphorus promotes the formation of calcified matrix and enhances bioactivity.

However, this method requires specialized equipment and is technically more complex than other physical surface treatments (Kim, et al., 2012).

APPLICATION OF BIOACTIVE COATINGS

The application of bioactive coatings to dental implant surfaces represents one of the most promising strategies to improve their integration with bone tissue and increase long-term clinical reliability. Bioactive coatings are specially engineered surfaces that, in addition to their physical and chemical properties, provide biological signals that stimulate cell adhesion, osteoblast proliferation and differentiation, and the formation of new bone matrix. These layers may consist of mineral phases, biological macromolecules, or bioactive nanoparticles.

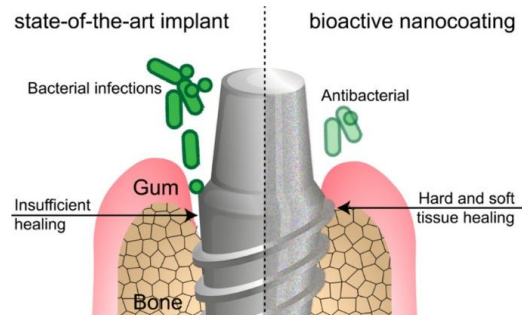


Figure 5. Principle of bioactive coatings (Zhang, et al., 2021).

Hydroxyapatite and Calcium Phosphates

The most widely used bioactive coating in dental implantology is hydroxyapatite (HA), the primary inorganic component of bone and teeth. HA surface layers can be applied using various techniques such as plasma spraying, sol-gel processing, or electrophoretic deposition. Hydroxyapatite coatings enhance osteoconduction, thereby accelerating implant osseointegration (Albrektsson, & Johansson, 2001). Calcium phosphates may also be applied in modified forms (e.g., tricalcium phosphate, fluorapatite), which improve chemical stability and resistance to dissolution in biological fluids. These coatings also stimulate the formation of biomineral phases of the bone matrix at the implant interface (Lee, et al., 2015).

Immobilization of Proteins and Peptides

Another group of bioactive layers involves biomolecular surface modifications through the immobilization of proteins and peptides that naturally promote cell adhesion. A typical example includes RGD peptides (arginine-glycine-aspartic acid), which are components of the extracellular matrix and bind to integrin receptors on osteoblasts (Ruoslahti, 1996). Immobilized proteins such as fibronectin, laminin, or vitronectin enhance specific interactions between the implant and cells, leading to improved proliferation and differentiation of osteogenic cells (Schliephake et al., 2009). These bioactive coatings can be applied through chemical bonding (e.g., via silane linkers) or physical adsorption.

Nanomaterials and Nanostructured Coatings

With the advancement of nanotechnology, research has increasingly focused on applying nanostructured bioactive coatings characterized by a high specific surface area and unique interactions with cells. Titanium nanolayers, calcium nanoparticles, nanoapatites, or collagen nanofibers can be applied using electrophoretic deposition, layer-by-layer assembly, or self-assembling monomolecular films (Zhao, et al., 2010). These nanostructures mimic the natural nanoarchitecture of the bone matrix and provide physical and chemical stimuli that strongly support osteoblastic differentiation while potentially reducing bacterial adhesion Webster, et al., 2000).

Biofunctional Surface Modifications with Biological Factors

Incorporating growth factors and biologically active molecules into the implant surface layer enables localized stimulation of tissue regeneration. The most commonly used include BMP-2

(bone morphogenetic protein-2), which promotes new bone formation, and VEGF (vascular endothelial growth factor), which supports angiogenesis (Schliephake, 2012). These factors can be directly bound to the implant or delivered via carriers such as hydrogels, enabling gradual release and prolonged effect. Such biofunctional coatings significantly improve the potential for rapid and high-quality osseointegration, especially in compromised tissue conditions.

RESULTS AND DISCUSSION

Selecting the appropriate surface modification technique for dental implants is a critical decision that significantly influences the biological response, quality of osseointegration, and long-term clinical success of the implant. Each technique has its own advantages, limitations, and clinical indications, depending on the specific scenario, the type of material used (particularly titanium and its alloys), and the patient's biological profile.

Mechanical techniques such as sandblasting and acid etching (especially the SLA technique – sandblasted, large grit, acid-etched) are currently considered the gold standard for routine clinical applications. They create micro- and macro-scale roughness, increasing surface area, improving mechanical anchorage of the fibrin network, and promoting early osteoblast colonization (Wennerberg & Albrektsson, 2010). Their advantages include proven long-term clinical reliability and ease of process reproducibility. However, disadvantages include the risk of residual abrasive particles and limited ability to actively modulate biological processes, which is particularly important in patients with impaired healing capacity (e.g., diabetics, smokers) (Chrcanovic, et al., 2015).

In contrast, chemical treatments such as anodization or alkaline treatment with heat processing deliberately modify the surface's chemical and electrical properties, enhancing its reactivity and promoting early-phase apatite formation during healing (Kokubo & Takadama, 2006). These techniques create a bioactive interface capable of ion exchange and selective protein adsorption. Additionally, they allow for the integration of functional groups that can influence the direction of cellular differentiation. Potential drawbacks include higher technological demands and the need for precise control over processing conditions (Sul, et al., 2002).

Physical methods such as plasma treatment or laser texturing can alter surface energy and nanostructure without direct material contact. Plasma activation significantly increases surface hydrophilicity, promoting the initial adhesion of osteoprogenitor cells and the expression of osteogenic markers (Canullo, et al., 2017). Laser texturing, on the other hand, enables the creation of precisely defined micro- and nanopatterns that influence cytoskeletal arrangement and cell morphological orientation (Scarano, et al., 2003). These methods appear promising, especially in personalized implantology, but require sophisticated equipment and standardized parameters. The application of bioactive coatings such as hydroxyapatite, bioglass, or biologically active molecules (e.g., RGD peptides, BMP-2) provides an additional level of interaction between the implant and host tissue. These coatings can actively stimulate osteoblastic differentiation and angiogenesis (Hench, 2006; Schliephake, et al., 2009). While plasma-sprayed HA coatings previously suffered from delamination and low adhesion to titanium, modern techniques such as sol-gel or electrophoretic deposition have significantly improved the quality and stability of these layers (Geetha, et al., 2009; Lee, et al., 2015). Their main limitations include potential immunological reactions or degradation of the coating under dynamic oral loading. Overall, there is no universal technique suitable for all clinical scenarios. Rather, an individualized approach is needed, considering the characteristics of host tissue, expected healing duration, presence of risk factors, and properties of the implant system used. Current trends favor multimodal strategies that combine multiple techniques (e.g., SLA + plasma activation + bioactive coating) to achieve synergistic stimulation of the biological response (Gomez-Florit, et al., 2021).

Table 1. Comparison of Dental Implant Surface Modification Techniques.

Technique	Description/ Principle	Advantages	Disadvantages	Indications
Mechanical Modifications (sandblasting, etching, SLA)	Creation of micro- and macro-roughness using abrasives and acids.	- Increased surface area - Enhanced fibrin anchorage - Early osseointegration - Proven clinical reliability	- Risk of residual abrasives - Low biological activity - Unsuitable in cases of impaired healing	Routine use, suitable for most patients
Chemical Treatments (anodization, alkaline and heat treatment)	Modification of chemical properties to promote cell adhesion and differentiation.	- Higher surface reactivity - Promotes apatite formation - Integration of functional groups	- Technologically demanding - Requires precise process control	Patients requiring enhanced bioactivity
Physical Methods (plasma, laser)	Non-contact surface nano-structuring to modulate cellular responses.	- Increased hydrophilicity - Precise micro/nanotexturing - Promotes cell orientation	- Requires sophisticated equipment - Need for parameter standardization	Personalized implantology, experimental applications
Bioactive Coatings (hydroxyapatite, bioglass, RGD, BMP-2)	Deposition of bioactive substances to stimulate cell activity.	- Osteoblast stimulation - Biocompatibility	- Risk of immune reactions - Coating degradation	Complex cases, patients with impaired healing

CONCLUSIONS

Surface modifications of dental implants play a crucial role in ensuring their biological compatibility, mechanical stability, and long-term clinical success. Given the diversity of materials used, each implant type requires a specific approach that considers its physical, chemical, and biological characteristics. Mechanical, chemical, and physical surface modification methods significantly influence the topography, surface energy, and chemical composition, directly enhancing cell adhesion, osteoblastic activity, and subsequent osseointegration. The application of bioactive coatings, including hydroxyapatite and nanostructured layers, represents an advanced strategy to increase implant bioactivity and stimulate bone tissue regeneration. In addition to supporting bone integration, appropriately selected surface treatments can modulate inflammatory and immune responses, thus reducing the risk of complications such as peri-implantitis. A key aspect is the individualization of surface modifications based on specific clinical conditions and patient-related systemic factors, including bone quality, the presence of chronic diseases, and other risk factors.

The future of dental implantology lies in the development of intelligent, multifunctional surfaces capable of adaptively responding to changes in the biological microenvironment, thereby improving implant functionality and longevity. The integration of advanced material technologies with clinical strategies leads to optimized treatment outcomes and improved patient quality of life. A systematic connection between experimental research and clinical practice is essential for the effective translation of innovations into routine use in implant dentistry.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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PSYHOLOGY
PSIHOLOGIJA

ODNOS RIGIDNOSTI, PERFEKCIONIZMA I MENTALNOG ZDRAVLJA

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SAŽETAK

Rigidnost je jedan od najstarijih psiholoških konstrukata, za koji se danas, u literaturi, vezuju osobine poput egocentrizma, autoritarnosti, opsesivnosti, nefleksibilnosti i slično. Sa stanovišta psihijatrije, rigidna osoba nije bolesna osoba već normalna, zdrava osoba sa posebnom crtom ličnosti. Cilj ovog istraživanja bio je da se utvrdi da li je rigidnost kao crta ličnosti statistički značajno povezana sa perfekcionizmom i opštim stanjem mentalnog zdravlja, mjerenim preko parametara nivoa stresa, anksioznosti i depresivnosti. Uzorak je činilo 212 ispitanika, od kojih je 110 bilo ženskog, a 102 muškog pola. Od instrumenata su korišćeni sljedeći mjerni instrumenti: Strukturirani upitnik za sociodemografske podatke (konstruisan za potrebe ovog istraživanja), Breskinova skala rigidnosti, Burnsova skala perfekcionizma, Kratki upitnik mentalnog zdravlja (MHI-5), Skala depresivnosti, anksioznosti i stresa (DASS).

Rezultati istraživanja nisu otkrili značajnu povezanost između rigidnosti, perfekcionizma i različitih aspekata mentalnog zdravlja, što nije u skladu sa predstavljenim teorijskim postavkama i prethodnim istraživanjima. Međutim, dobijeni rezultati su pokazali da postoji razlika među ispitivanim konceptima u odnosu na pol, pri čemu muškarci pokazuju znatno veći nivo rigidnosti ($p=.01$) i perfekcionizma ($p=.05$) u odnosu na žene. Utvrđene su statistički značajne razlike između nivoa rigidnosti i varijable „starost“ ($p=.05$): stariji ispitanici u uzorku su rigidniji u svom ponašanju u odnosu na mlađe ispitanike. Takođe, istraživanje je pokazalo da ispitanici iz predgrađa, kao mjesta prebivališta, produkuju veći nivo depresivnosti i stresa u odnosu na ispitanike sa sela i iz grada, dok u odnosu na varijablu „stres“ nisu nađene statistički značajne razlike.

Ključne riječi: rigidnost, perfekcionizam, mentalno zdravlje.

UVOD

Rigidnost kao psihološki konstrukt se eksponira kao veoma atraktivan za istraživanje među psiholozima. Na ovo ukazuje činjenica da se, u periodu od 1967. godine do 1998. godine, kako navodi Grahovac (2020), ovaj konstrukt našao u 1733 naslova ili apstrakta, a od 1999. godine do 2020. godine u 639 naslova ili apstrakta. Sam termin je latinskog porijekla i u bukvalnom prevodu znači nepokretnost, nepromenljivost, krutost (Svitkevich, 2022). Psihoanaliza je mentalnu krutost shvatila kao pacijentov otpor prema promjeni ili situaciji koju želi izbjeći (Narda, 2018). Ne postoji jedna sveobuhvatna definicija ovog konstrukta: kroz historiju proučavanja, ovaj pojam je bio različito definisan, a danas se, uglavnom, osobina rigidnosti pripisuje osobama koje pokazuju krutost u stavovima, ne razumiju stajališta različita od vlastitog i odbijaju drugačije ideje, mišljenja i perspektive.

Kod definisanja rigidnosti akcenat je na ponavljanju „šablona“ koje neka osoba koristi. Pri tom se polazi od pretpostavke da nije u pitanju samo crta ličnosti, već da su u ovaj sistem ponašanja uključeni i kognitivni stil neke osobe, njen referentni sistem, način emotivnog reagovanja, slika o sebi i drugima, kao i sistem vrijednosti date osobe (Grahovac, 2011).

Najjednostavniju definiciju perfekcionizma ponudili su Flett i Hewitt (2016), definirajući ga kao težnju za savršenstvom i nepogrešivosti u svim aspektima života (Dujmović, 2014). Perfekcionizam se može definisati i kao crta ličnosti koju karakteriziraju tendencija za stvaranjem i održavanjem ekstremno visokih standarda te pojačane kritičke evaluacije vlastitog ponašanja ili izvedbe. Prema Dmitroviću (2015), postoji mnogo negativnih karakteristika koje se vezuju uz perfekcionizam, kao što su povećana vulnerabilnost za različite oblike psihopatologije, povećani stres, anksioznost, depresiju.

Mentalno zdravlje čovjeka predstavlja sastavni, funkcionalni dio njegove ličnosti, ponašanja i prilagođavanja u sociokulturnoj i ekološkoj sredini. Jovičević (1985) navodi da mentalno zdravlje i tjelesno zdravlje predstavljaju opšti pojam zdravlja i vrlo teško ih je podvajati, ali i definisati. Danas se mentalno zdravlje sve više nastoji odrediti pomoću više različitih kriterija koji egzistiraju istovremeno. Ti kriteriji mentalno zdravlje najčešće određuju kao: prosjek, odsustvo bolesti, socijalnu prihvatljivost i ideal (Miković, 2007).

Prema definiciji Svjetske zdravstvene organizacije, mentalno zdravlje podrazumijeva stanje dobrobiti u kojem pojedinac ostvaruje svoje potencijale, može se nositi s normalnim životnim stresom, može raditi produktivno i plodno, te je sposoban pridonositi zajednici (WHO, 2001). Mentalno zdravlje čovjeka je u kriznim i stresnim situacijama kontinuirano ugroženo usljed promjena u spoljnoj sociokulturnoj i ekološkoj sredini, ali i zbog osujećenja u zadovoljavanju njegovih vitalnih motiva i potreba. Stresori različito djeluju na različite ljude i izazivaju različite reakcije, te se može reći da upravo od karakteristika ličnosti zavisi način doživljavanja i reagovanja na stresore. Svaka osoba tokom svog životnog vijeka doživi osjećaj stresa i anksioznosti. Wenar (2003) ističe da anksioznost ima brojne definicije. Prema jednoj od njih, anksioznost je psihološko, fiziološko i ponašajno stanje, koje je inducirano aktualnom ili potencijalnom opasnosti (Schore, 1997, prema Gregurek, Ražić Pavičić i Gregurek, 2017). Ona nije nužno negativno stanje i, u tzv. normalnim okolnostima, može imati podsticajni karakter, dok patološku anksioznost karakterizira ekcesivnost, pervazivnost i nemogućnost kontrole (Grgurek i saradnici, 2017). S druge strane, depresija podrazumijeva psihički poremećaj, čija su bitna obilježja promjene raspoloženja, utučenost, pomanjkanje radosti, osjećajna praznina, bezvoljnost, gubitak interesa i niz tjelesnih tegoba. Ona je, poput anksioznosti i srdžbe, fenomen koji doživljava većina ljudi, pa stoga intenzitet ispoljavanja ovih tegoba govori o tome, da li je ovo stanje psihopatološko ili ne.

Dosadašnja istraživanja veze između rigidnosti, perfekcionizma i mentalnog zdravlja

Pregledom literature istraživao je složeni odnos između rigidnosti i perfekcionizma, te povezanost sa stresom, anksioznošću i depresijom u kontekstu mentalnog zdravlja. Kroz analizu niza relevantnih istraživanja, razmatrano je kako su povezani ispitivani koncepti.

Grahovac (2011) je sprovela istraživanje o relaciji koncepta rigidnosti sa dimenzijama ličnosti mjerenim upitnikom "Velikih pet plus dva (VP+2). Rezultati pokazuju da je dobijena značajna pozitivna povezanost ($p < .01$) između starosti i rigidnosti. Dobijeni rezultati su pokazali da je rigidnost značajno povezana sa bazičnim dimenzijama ličnosti.

Svitkovich (2022) ističe da se rigidnost smatra bitnom komponentom disfunkcionalnog, tj. neurotskog perfekcionizma. Stoga se i sama rigidnost definira kao otpor prema sticanju novih obrazaca ponašanja uz zadržavanje starih, neprilagodljivih ponašanja. Također, Grahovac (2020) navodi da se rigidnost često spominje u kontekstu perfekcionizma, čiji se ekstremni skorovi povezuju sa nekim psihopatološkim kategorijama (poremećaji ishrane, depresija, suicidalnost). Fedewa, Burns i Gomez (2005, prema Dmitrović, 2015) ističu da negativan perfekcionizam značajno korelira s kategorijalnim razmišljanjem, odnosno crno-bijelim gledanjem na svijet, netolerancijom i nepovjerenjem u druge.

Pojedina istraživanja su pokazala da rigidnost može doprinijeti razvoju psihopatoloških simptoma jer ograničava sposobnost pojedinca da se prilagodi promjenama i izazovima u životu (Davis i Williams, 2019). Zatim, Morris i Mansell (2018) pružaju sistematski pregled odnosa između rigidnosti i fleksibilnosti u kontekstu održavanja psihopatologije. Njihova analiza sugerise da infleksibilnost u primjeni kognitivnih i bihevioralnih procesa može biti ključna za razumijevanje psihološkog stresa i simptoma. Ove informacije ukazuju na to da rigidnost može doprinijeti održavanju psihopatoloških stanja, kao što su anksioznost i depresija, dok fleksibilnost može igrati

ključnu ulogu u očuvanju mentalnog zdravlja. Ova studija ukazuje na potrebu za razumijevanjem kako rigidnost može uticati na emocionalno stanje pojedinca.

Prema istraživanju Flett-a i Hewitt-a (2016), rigidnost u kombinaciji sa maladaptivnim perfekcionizmom povećava rizik od emocionalnog distresa kod osoba koje se suočavaju sa visokim zahtjevima. Iako je perfekcionizam povezan sa visokim postignućima, prilagodljivim suočavanjem i savjesnošću, sve veći broj istraživanja pokazuje kako su osobe sklone perfekcionizmu ranjivije na razne oblike psihičkih poteškoća, tj. anksioznost, depresiju i ljutnju (Di Schiena i saradnici, 2012, prema Krasnić, 2022).

Perfekcionista, prema rezultatima mnogih istraživanja spadaju u skupinu pojedinaca s nefleksibilnim načinom razmišljanja, tj. razmišljaju samo u terminima apsolutnog uspjeha ili neuspjeha (Burns i Fedewa, 2005, prema Dmitrović, 2015). Takav način razmišljanja i djelovanja često vodi do izraženijeg stresa, prisustva anksioznosti i depresije. Također, takav način razmišljanja potvrđuje prisustvo crta rigidnosti i svu težinu funkcionisanja pojedinca koju rigidnosti sa sobom donosi. Sve više do izražaja dolaze rigidne granice koje je pojedinac postavio kao zaštitni oklop od okoline.

McKinney Clark (2019) se fokusira na istraživanje uloge psihološke fleksibilnosti i infleksibilnosti u kontekstu perfekcionizma među studentima i klijentima u savjetovanju. Nalazi sugerisu da maladaptivni perfekcionizam može predvidjeti psihološku infleksibilnost, što može dodatno pojačati simptome depresije i anksioznosti.

Rozental (2020) se bavi terapijskim pristupima u radu sa perfekcionizmom, ukazujući na to kako rigidnost u postavljanju nerealnih ciljeva može negativno uticati na međuljudske odnose i mentalno zdravlje. Njegova analiza razdvaja perfekcionistačke brige i težnje, pokazujući kako oba aspekta imaju različite implikacije na psihopatologiju. Dakle, ovo istraživanje pruža uvid u to kako perfekcionizam može uticati na međuljudske odnose i mentalno zdravlje, ističući da rigidna postavka standarda može rezultirati emocionalnim teškoćama i samokritikom, što je povezano sa depresijom i anksioznošću. Takođe, ukazuje na potrebu za holističkim pristupom u razumijevanju perfekcionizma kao multidimenzionalnog konstruktivnog fenomena.

Zhang i saradnici (2021) istražuju ulogu perfekcionizma u razvoju depresivnih simptoma među studentima, naglašavajući da rigidni kognitivni obrasci mogu doprinijeti negativnim emocijama i stresu. Njihova istraživanja ukazuju na važnost razumijevanja pozitivnih i negativnih dimenzija perfekcionizma u kontekstu mentalnog zdravlja.

METOD

Problem i cilj istraživanja

Iako je rigidnost jedan od najstarijih psiholoških konstrukata, još uvijek postoje mnoge nejasnoće u njegovom definisanju i načinu mjerenja. Može se reći da postoji izvjesna konfuzija u upotrebi ovog termina, a sam fenomen se može ispitivati na različitim nivoima mentalnog funkcionisanja: na nivou ličnosti, emocija, karaktera, u okviru stavova... U svakom slučaju, ovaj pojam se odnosi na ponavljanje „šablona“ koje neka osoba ima a koji se odnose na to kako ona doživljava sebe i druge, te se ispoljava u svim kontekstima funkcionisanja te osobe, pri čemu osoba ne mijenja način funkcionisanja, čak i kada se sredina promjeni. S druge strane, perfekcionizam obuhvata načine ponašanja i tipove ličnosti u kojima postoji težnja za savršenstvom i nepogrešivosti, a uz koju postoji i tendencija ka postavljanju previsokih i osobi nedostižnih životnih ciljeva. Na kraju, mentalno zdravlje čovjeka predstavlja sastavni, funkcionalni dio njegove ličnosti, ponašanja i prilagođavanja u sociokulturnoj i ekološkoj sredini, a sve veća medijska prisutnost ove teme govori o njegovoj važnosti.

Vodeći se teorijskim definisanjem pojma rigidnosti od strane više autora (s obzirom da je slabo istražena i opisana pojava), te rezultatima dosadašnjih studija u radu je, preko parametara zastupljenih u upitničkom materijalu, kao predmet istraživanja, postavljeno ispitivanje veza rigidnosti i perfekcionizma, te rigidnosti i mentalnog zdravlja.

U tom kontekstu, cilj istraživanja je bio da se utvrdi postoje li statistički značajne razlike između ispitanika različitih sociodemografskih obilježja u odnosu na stepen izraženosti

Samardžić, S. i Blažević Smajlović, Dž. (2025). Odnos rigidnosti, perfekcionizma i mentalnog zdravlja. *STED Conference 14(2)*, 325-338.

rigidnosti, te da li će se, na ispitivanom uzorku, pokazati statistički značajna povezanost između rigidnosti, perfekcionizma i mentalnog zdravlja.

Hipoteze

Na osnovu defenisanog problema i ciljeva istraživanja, određene su i hipoteze ovog istraživanja:

H1: Očekuje se da postoji statistički značajna povezanost između nivoa rigidnosti, nivoa perfekcionizma i nivoa opšteg mentalnog zdravlja na našem uzorku.

H1-a: Pretpostavljamo da će ispitanici sa većim stepenom rigidnosti pokazati i veći stepen perfekcionizma.

H1-b: Očekujemo da će ispitanici sa većim stepenom rigidnosti pokazati i veći stepen depresivnosti.

H1-c: Očekujemo da će ispitanici sa većim stepenom rigidnosti pokazati i veći stepen anksioznosti.

H1-d: Očekujemo da će se kod ispitanika sa većim stepenom rigidnosti pojaviti i veći stepen stresa.

H1-e: Pretpostavljamo da će ispitanici sa većim stepenom rigidnosti pokazati niži stepen opšteg mentalnog zdravlja.

H2: Očekuje se da postoje statističke značajne razlike između ispitanika različitih sociodemografskih obilježja u odnosu na nivo izraženosti rigidnosti, nivoa perfekcionizma i nivoa opšteg mentalnog zdravlja na našem uzorku.

H2-a: Očekuje se da žene postižu veće skorove na perfekcionizmu i anksioznosti, dok muškarci postižu veće skorove na rigidnosti.

H2-b Očekuje se da mlađi ispitanici imaju veće skorove na perfekcionizmu, dok stariji ispitanici imaju veće skorove na rigidnosti.

H2-c: Očekuje se da ispitanici nižeg socioekonomskog statusa i iz ruralnih područja, mogu imati niži stepen opšteg mentalnog zdravlja.

H2-d: Očekuje se da prvorodeni ispitanici imaju veće skorove na perfekcionizmu u odnosu na ostale ispitanike.

Uzorak i procedura

Uzorak istraživanja čini 212 odraslih ispitanika, od toga 110 žena i 102 muškarca. Starost ispitanika se kretala u rasponu od 18 do 71 godine, a prosječna starosna dob cjelokupnog uzorka je 33,7 godina. Najveći broj ispitanika živi u gradskoj sredini (49.5%), srednjoškolskog je obrazovanja (50.9%) i u braku je (51.4%).

Istraživanje je sprovedeno u nekoliko faza. Najprije smo navedene upitnike pretvorili u online formu, uz pomoć aplikacije Google Forms. Zatim smo definisali uzorak istraživanja: u istraživanju su mogli učestvovati ispitanici oba pola, sa starosnim rasponom od 18 do 75 godina. Dodatnih kriterijuma nije bilo.

Prikupljanje podataka vršeno je na dva načina: direktno (licem u lice) i online (Facebook, Viber, Instagram, WhatsApp). Svim ispitanicima je ukratko objašnjena sama svrha istraživanja, kao i način i upute popunjavanja upitnika, sa naglaskom da je istraživanje potpuno anonimno. Za popunjavanje upitnika je bilo potrebno otprilike oko 20 minuta.

Instrumenti

U istraživanju su korišćeni sljedeći mjerni instrumenti:

- *Strukturisani upitnik za sociodemografske podatke*: sadrži podatke o: polu i starosti ispitanika, redoslijedu rođenja, stepenu obrazovanja, mjestu trenutnog stanovanja, bračnom statusu.
- *Breskinova skala rigidnosti*: riječ je o skali rigidnosti neverbalnog tipa, u čijoj su osnovi načela preferencije različitih perceptivnih sadržaja. Skala se sastoji od 15 čestica: to su u stvari parovi vizuelno različitih simbola koji su, u smislu perceptivne organizacije,

konstruirani prema gestalt načelima, odnosno prema Pragnanzovom zakonu (koji podrazumijeva tendenciju ljudi ka pojednostavljivanju oblika, tendenciju ka „kompletnosti“ oblika, i sl.): u tom smislu, jedan od simbola u paru „poštuje“ ova načela, dok ih drugi simbol „krši“. Kod svakog para simbola ispitanik bira onaj, koji mu se više sviđa, a svoj odabir obilježava zaokruživanjem izabranog simbola. Rezultat na skali rigidnosti tretira se kao jednostavna aditivna linearna kombinacija svih čestica vodeći računa o smjeru čestica, a pojedini odgovori vrednuju se kao 1 bod za odgovor koji ukazuje na manju rigidnost, 2 boda za odgovor koji ukazuje na veću rigidnost (Proroković, 2004).

- *Burnsova skala perfekcionizma*: mjeri perfekcionizam usmjeren prema sebi (Burns, 1980, prema Ivanov i Penezić, 2004). Skala sadrži 10 čestica na koje se odgovara na skali Likertova tipa s pet stepena. Ukupni rezultat formira se kao linearna kombinacija procjena (Ivanov i Penezić, 2004).
- *Kratki upitnik mentalnog zdravlja (MHI-5)*: sastoji se od samo 5 čestica, odabranih na temelju teorijskog uporišta (namjera je bila da se što manjim brojem čestica obuhvate osnovni domeni mentalnog zdravlja) te empirijskih podataka (rezultata faktorskih i regresijskih analiza). Razvili su ga Davies, Sherbourne, Peterson i Ware 1988. godine (Slišković, 2020), a nastao je kao kratka verzija Inventara mentalnog zdravlja, koji se izvorno sastoji od 38 čestica (svrstanih u šest subskala). Zadatak ispitanika je procijeniti učestalost za svako od pitanja (od 1 = *stalno* do 6 = *nikad*), pri čemu je uputom naglašeno da se procjenjuje period od proteklih mjesec dana. Upitnik uključuje ispitivanje domena anksioznosti, depresivnosti, opšteg pozitivnog afekta i bihevioralne/emocionalne kontrole. Ukupni rezultat se, uz obrnuto bodovanje dviju čestica kojima se ispituje opšti pozitivni afekt (čestice 2 i 5), formira kao zbroj rezultata na svim česticama, pri čemu viši rezultat upućuje na višu razinu opšteg mentalnog zdravlja (Slišković, 2020). Uprkos malom broju čestica, ovaj upitnik pokazuje dobra psihometrijska svojstva, a korelacija između ukupnog rezultata na Kratkome upitniku mentalnog zdravlja i ukupnog rezultata na Inventaru mentalnog zdravlja, prema navodima Slišković (2020) iznosi .95.
- *Skala depresivnosti, anksioznosti i stresa (DASS)*: sastoji od 42 čestice, koje su svrstane u tri subskale: subskalnu depresivnosti, subskalnu anksioznosti i subskalnu stresa. Subskala depresivnosti se odnosi na simptome disforije, apatije, beznadežnosti i gubitak interesovanja za životna zadovoljstva. Subskalom anksioznost se mjere simptomi pobuđenosti autonomnog nervnog sistema i situaciona anksioznost, dok subskala stresa ispituje prisustvo simptoma uznemirenosti, nesposobnost opuštanja, nestrpljenje, i sl. Ispitanici odgovaraju zaokruživanjem odgovarajućeg broja na skali Likertova tipa s četiri stepena. Ukupan rezultat se oblikuje kao linearna kombinacija procjena po pojedinim subskalama (Reić Ercegovac i Penezić, 2012).

REZULTATI

Za potrebe obrade podataka na našem uzorku, deskriptivnom statistikom smo dobili rezultate aritmetičke sredine, standardne devijacije, minimum i maximum. Pomoću Kronbah-alfa testa je provjeren nivo pouzdanosti skale, dok se pomoću Kolmogorov-Smirnovog provjerila normalnost, odnosno utvrđeno je da se odgovori na skalama ne distribuiraju normalno, pa su zbog toga naredni primjenjeni postupci bili neparametrijski (Spirmanov koeficijent korelacije, Mann-Whitney U test, Kruskal Wallis test).

Tabela 1. Prikaz deskriptivnih podataka ispitivanih koncepata.

Table 1. Display of descriptive data of examined concepts.

	Min	Max	AS	SD	α	p K-S
Rigidnost	16	30	24.92	2.78	0.76	0.00
Perfekcionizam	1	5	3.31	1.13	0.91	0.00
Depresivnost	1	4	1.78	0.97	0.97	0.00
Anksioznost	1	4	1.90	0.91	0.96	0.00
Stres	1	4	2.15	0.92	0.95	0.00
Opšte mentalno zdravlje	1	6	3.82	1.41	0.90	0.00

*Min – minium; Max – maksimum; AS – aritmetička sredina; SD – standardna devijacija; α - pouzdanost; p K-S- značajnost Kolmogorov-Smirnov statistika

Na osnovu podataka iz tabele 1, uslovno se može reći da su empirijske aritmetičke sredine oko teorijskog prosjeka skale, osim za skalu Perfekcionizam (AS=3.31; SD=1.13), koja je nešto viša.

Tabela takođe sadrži podatke o pouzdanosti primenjenih skala, koji ukazuju da je pouzdanost skale Rigidnosti nešto ispod prihvaćene granice pouzdanosti ($\alpha=0,76$), ali imajući u vidu da je ovo test neverbalnog tipa i sa malim brojem čestica moglo bi se reći da je pouzdanost ipak prihvatljiva. Ostale skale imaju visoki nivo pouzdanosti ($\alpha > 0.9$).

Prvom hipotezom ispitivali smo očekivanje da postoji statistički značajna povezanost između nivoa rigidnosti, nivoa perfekcionizma i nivoa opšteg mentalnog zdravlja u našem uzorku. Prikaz dobijenih rezultata dat je u tabeli 2.

Tabela 2. Prikaz korelacione analize.

Table 2. Presentation of correlation analysis.

	Rigidnost	Perfekcionizam	Depresivnost	Anksioznost	Stres	Opšte mentalno zdravlje
Rigidnost	1	0.08	0.05	0.05	0.08	-0.02
Perfekcionizam	0.08	1	0.46**	0.49**	0.51**	-0.43**
Depresivnost	0.05	0.46**	1	0.84**	0.80**	-0.66**
Anksioznost	0.05	0.49**	0.84	1	0.87**	-0.62**
Stres	0.08	0.509**	0.802**	0.865**	1	-0.62**
Opšte mentalno zdravlje	-0.02	-0.43**	-0.62**	-0.62**	-0.62**	1

* $p < 0.05$; ** $p < 0.01$

Podaci o ispitanoj povezanosti govore da:

- Rigidnost ne korelira statistički značajno ni sa jednim drugim konceptom ($p > 0.05$).
- Perfekcionizam gradi statistički značajne pozitivne korelacije, sa varijablom Depresivnost (0.46; $p < 0.01$), Anksioznost (0.49; $p < 0.01$) i Stres (0.51; $p < 0.01$) i negativnu sa Opštim mentalnim stanjem (-0.43; $p < 0.01$).
- Depresivnost statistički značajno pozitivno korelira sa Anksioznošću (0.84; $p < 0.01$) i Stresom (0.80; $p < 0.01$) i negativno sa Opštim mentalnim zdravljem (-0.66; $p < 0.01$).
- Anksioznost statistički značajno pozitivno korelira sa Stresom (0.87; $p < 0.01$) i statistički značajno, negativno sa Opštim mentalnim zdravljem (-0.62; $p < 0.01$).
- Stres statistički značajno, negativno korelira sa Opštim mentalnim zdravljem (-0.62; $p < 0.01$).

Dobijene korelacije iz tabele 2, ukazuju da, ako je kod ispitanika izraženiji perfekcionizam biće prisutniji simptomi depresije, anksioznosti i stresa, a opšte mentalno stanje će biti nižeg kvaliteta. Takođe, ukoliko je kod osobe prisutnije depresivno raspoloženje, onda će biti prisutniji i simptomi anksioznosti i doživljenog stresa (i obratno za sve tri dimenzije). I na kraju, ukoliko su kod osobe prisutniji simptomi depresije, anksioznosti i doživljenog stresa, opšta ocjena mentalnog zdravlja će biti niža.

Druga hipoteza odnosila se na ispitivanje statistički značajnih razlika između ispitanika različitih sociodemografskih obilježja u odnosu na nivo izraženosti rigidnosti, perfekcionizma i opšteg mentalnog zdravlja u uzorku. U tabeli 3 vidimo prikaz razlika u ispitivanim konceptima u odnosu na pol.

Tabela 3. Prikaz razlike u ispitivanim konceptima u odnosu na pol.

Table 3. Presentation of the difference in examined concepts in relation to gender.

	Pol	Prosječni rang	Mann-Whitney U test	P
Rigidnost	Muški	117.80	4457.00	0.01
	Ženski	96.02		
Perfekcionizam	Muški	115.22	4721.00	0.05
	Ženski	98.42		
Depresivnost	Muški	105.51	5509.50	0.82
	Ženski	107.41		
Anksioznost	Muški	100.78	5027.00	0.19
	Ženski	111.80		
Stres	Muški	104.01	5356.50	0.57
	Ženski	108.80		
Opšte mentalno zdravlje	Muški	107.92	5465.00	0.75
	Ženski	105.18		

p – statistička značajnost

Pregledom rezultata može se uočiti da postoji statistički značajna razlika između muškaraca i žena na varijablama Rigidnost (4457; $p=0.01$) i Perfekcionizam (4721; $p=0.05$). Rezultati ukazuju da muški ispitanici u našem uzorku manifestuju rigidnije ponašanje i skloniji su perfekcionizmu u odnosu na žene.

Što se tiče varijable starost, podaci iz Tabele 4 pokazuju da je statistički značajna povezanost dobijena samo sa varijablom Rigidnost (0.14; $p<0.05$), dok sa ostalim varijablama ne postoji statistički značajna veza ($p>0.05$). Dobijena povezanost signalise da su stariji ispitanici iz uzorka rigidniji u svom ponašanju u odnosu na mlađe ispitanike.

Tabela 4. Prikaz povezanosti starosti i ispitivanih koncepata.

Table 4. Presentation of the relationship between age and examined concepts.

	Starost
Rigidnost	0.14*
Perfekcionizam	0.07
Depresivnost	0.04
Anksioznost	0.03
Stres	-0.01
Opšte mentalno zdravlje	-0.01

* $p<0.05$

U Tabeli 5 dati su rezultati ispitivanja statističke značajnosti razlika između ispitivanih koncepata u odnosu na mjesto stanovanja.

Tabela 5. Prikaz razlike u nivou izraženosti ispitivanih koncepata u odnosu na mjesto stanovanja.

Table 5. Presentation of the difference in the level of expression of the examined concepts in relation to the place of residence.

	Mjesto stanovanja	Prosječni rang	Kruskal Volis test	P
Rigidnost	Selo	111.32	1.36	0.51
	Predgrađe	111.35		
	Grad	101.58		
Perfekcionizam	Selo	99.82	5.23	0.07
	Predgrađe	126.50		
	Grad	103.40		
Depresivnost	Selo	106.30	6.00	0.05
	Predgrađe	126.96		
	Grad	99.03		
Anksioznost	Selo	103.14	10.54	0.01
	Predgrađe	134.88		
	Grad	98.13		
Stres	Selo	102.01	6.03	0.05
	Predgrađe	128.27		
	Grad	101.32		
Opšte mentalno zdravlje	Selo	109.46	1.95	0.38
	Predgrađe	94.13		
	Grad	109.18		

* p – statistička značajnost

Nađena je statistički značajna razlika između ispitanika različitog mjesta stanovanja u odnosu na varijable Depresivnost (6; $p=0.05$), Anksioznost (10.54; $p=0.01$) i Stres (6.03; $p=0.05$), dok je upoređivanje ispitanika po kategorijama varijable (svaka sa svakom) naknadno urađena i statistički značajne razlike prikazane su u Tabeli 6.

Kao što se iz tabele 6 vidi, statistički značajne razlike dobijene su između ispitanika iz predgrađa i onih iz gradova, i to na varijabli Depresivnost (27.93; $p<0.05$), a između ispitanika iz predgrađa i grada (36.75; $p<0.05$) i predgrađa i sela (-37.75; $p<0.05$) na varijabli Anksioznost. Prema dobijenim podacima, možemo zaključiti da su ispitanici iz predgrađa i depresivniji i anksiozniji u odnosu na ispitanike poređene grupe.

Tabela 6. Prikaz poređenja svake kategorije mjesta stanovanja sa svakom na varijablama gdje je dobijena statistički značajna razlika – Depresivnost, Anksioznost i Stres.

Table 6. Comparison of each category of place of residence with each of the variables where a statistically significant difference was obtained - Depression, Anxiety and Stress.

	Mjesto stanovanja	Test statistik	P
Depresivnost	Grad	Predgrađe	27.93
			0.04
Anksioznost	Grad	Predgrađe	36.75
	Selo		-37.75
			0.03

* p – statistička značajnost

Posmatrajući dalje, iz tabele 7 vidimo da u odnosu na red rođenja u porodici nema statistički značajnih razlika u odnosu na posmatrane varijable ($p>0.05$).

Tabela 7. Prikaz razlike u nivou izraženosti ispitivanih koncepata u odnosu na red rođenja.

Table 7. Presentation of the difference in the expression level of the examined concepts in relation to the order of birth.

	Red rođenja	Prosječni rang	Kruskal Volis test	p
Rigidnost	jedino dijete	116.03	3.22	0.36
	najstarije dijete	104.39		
	srednje dijete	119.76		
	najmlađe dijete	99.76		
Perfekcionizam	jedino dijete	92.21	3.90	0.27
	najstarije dijete	103.87		
	srednje dijete	122.93		
	najmlađe dijete	104.87		
Depresivnost	jedino dijete	117.39	2.89	0.41
	najstarije dijete	105.21		
	srednje dijete	117.76		
	najmlađe dijete	99.50		
Anksioznost	jedino dijete	118.53	3.73	0.29
	najstarije dijete	102.81		
	srednje dijete	120.64		
	najmlađe dijete	100.43		
Stres	jedino dijete	113.39	1.47	0.69
	najstarije dijete	105.49		
	srednje dijete	115.07		
	najmlađe dijete	101.56		
Opšte mentalno zdravlje	jedino dijete	90.21	3.16	0.37
	najstarije dijete	114.43		
	srednje dijete	100.11		
	najmlađe dijete	105.09		

* p – statistička značajnost

DISKUSIJA

Sprovedeno istraživanje imalo je za cilj da ispita povezanost između rigidnosti, perfekcionizma i opšteg mentalnog zdravlja, s posebnim fokusom na stres, anksioznost i depresiju. Teorijski okvir istraživanja obuhvata definisanje rigidnosti kao karakteristike ličnosti koja se ogleda u krutosti mišljenja, ponašanja i emocija (Nikolić Maksić & Ljuljić, 2012). Perfekcionizam se posmatra kao težnja ka postizanju visokih standarda uz pojačanu samokritičnost (Klarica, 2020), dok je mentalno zdravlje definisano kroz komponente stresa, anksioznosti i depresije koje značajno utiču na kvalitet života.

Prva opšta hipoteza odnosila se na ispitivanje povezanosti nivoa rigidnosti, nivoa perfekcionizma i nivoa opšteg mentalnog zdravlja na našem uzorku. Pretpostavka da će ispitanici sa većim stepenom rigidnosti pokazati i veći stepen perfekcionizma nije se potvrdila (H1-a). Naime, istraživanjem nisu nađene statistički značajne korelacije između rigidnosti i perfekcionizma, što nije u skladu sa ranijom teorijom i istraživanjima. Na primjer, Frost i saradnici (Frost, et al., 1990) navode da visoki standardi i stroga samoevaluacija, koje karakterišu perfekcionista, mogu biti povezani sa rigidnim obrascima mišljenja. Ovdje dobijeni nalazi nisu u skladu sa istraživanjem Zanga i saradnika (Zhang, Liu i Wang, 2021) i radom Fleta i Hjuita (Flett & Hewitt, 1991), koji su istakli da rigidni obrasci mišljenja otežavaju prilagodljivost i podstiču perfekcionistačke tendencije. Takođe, Lezi (Lezzi, 2021) objašnjava da kognitivna rigidnost isključuje alternativna gledišta, što može doprinijeti izraženom perfekcionizmu. S obzirom da se perfekcionizam povezuje sa težnjom ka savršenstvu, možda upravo ovakvi nalazi upućuju da perfekcionistačke osoba razmišljaju slobodnije, kreativnije i fleksibilnije kako bi došle do ciljanog savršenstva, što je suprotno razmišljanju rigidne osobe, kako su nalazi i prikazali.

Istraživanjem takođe nije utvrđena statistički značajna povezanost između rigidnosti i depresivnosti (H1-b), pa ovi rezultati ne podržavaju teorije koje rigidnost povezuju s povećanom vulnerabilnošću na depresivne simptome. Na primjer, Svitkevich (2022) rigidnost opisuje kao osobinu koja otežava emocionalnu fleksibilnost i povećava vjerovatnoću razvoja depresije.

Neka starija istraživanja (Rokeach, 1948; Cowen, Thompson, 1951) su pokazala da rigidnost može otežati prilagodbu na nove situacije, što može povećati rizik od depresivnih stanja. Slično, i istraživanje Davisoma i Williamsoma iz 2019. godine ukazuje na to da rigidnost može ograničiti sposobnost prilagođavanja promjenama, što može dovesti do depresije. Grahovac (2020) također navodi da rigidne osobe često imaju veću sklonost ka osjećanju nezadovoljstva i depresiji zbog svojih krutih načina mišljenja i ponašanja. Mnoga istraživanja navode da postoji povezanost uticaja rigidnosti na razvoj depresivnosti, dok ovim nalazima to nije dokazano, što može značiti da rigidnost kao osobina može otežati prilagođavanje i narušiti normalno funkcionisanje individue, ali da je za njeno potvrđivanje ipak potreban nešto veći uzorak ispitanika.

Rezultati istraživanja nisu pokazali ni prisustvo statistički značajne povezanosti između rigidnosti i anksioznosti (H1-c), što nije u skladu sa nekim ranijim studijama. Jahier (2018), navodi da rigidno ponašanje ograničava spontano izražavanje emocija, što može dovesti do povećane anksioznosti. Takođe, Subotić (2014) naglašava da rigidni pojedinci često osjećaju snažan pritisak da sve bude savršeno, što povećava rizik od anksioznosti. Prema Svitkevich (2022), rigidne osobe često doživljavaju viši nivo anksioznosti zbog svoje nemogućnosti da se prilagode novim situacijama. Smatramo da bi se dobijeni nalazi mogli povezati sa mogućim obrambenim mehanizmima anksioznosti: moguće je da ispitanici, sa ciljem da se prikažu u što ljepšem i prilagodljivijem stanju potiskuju svoje istinsko stanje anksioznosti i bježe od problema dajući društveno poželjne odgovore. Ovo je vjerovatno u vezi sa činjenicom da anksiozne i rigidne osobe teško priznaju i pričaju o svom problemu. U opisu psihotipova s osobinom rigidnosti, Svitkovich (2022) je navela jedan od tipova koji svoje rigidno ponašanje izražava u izolaciji i želji da sakrije osjećaje, dok sa zadovoljstvom raspravlja o tuđim osjećajima.

Očekivanje da će ispitanici sa većim stepenom rigidnosti pokazati i veći stepen stresa (H1-d) nije se potvrdilo. Dosadašnji nalazi uglavnom ukazuju na to da su rigidniji pojedinci izloženi većem nivou stresa. Schmidt i saradnici (1954) ističu da rigidnost otežava proces adaptacije, što može povećati nivo stresa u uznemirujućim situacijama. Slične nalaze zabilježili su Morris i Mansel (2018): oni naglašavaju da kognitivna rigidnost može doprinijeti održavanju visokog nivoa stresa, što otežava prilagođavanje na stresne životne situacije. Narda (2018), u teorijskom razmatranju povezuje rigidnost s povećanom emocionalnom reakcijom na stresne događaje. Rezultati ovog istraživanja se mogu povezati sa tumačenjima kognitivne rigidnosti koje je dao Lezi (2021), a koji navodi da rigidne osobe često žive u određenoj mentalnoj dimenziji koja je izvan sadašnjosti. On objašnjava da su takve osobe podigle barikade prema novim događajima i tumačenjima, te ih ne dotiču nove promjene jer se čvrsto drže svog načina razmišljanja. Stoga je vrlo moguće da svakodnevni stres ne probija njihove barikade i granice, pa se u ovom pravcu mogu tumačiti i naši rezultati.

Odbačena je i naša pretpostavka da će ispitanici sa većim stepenom rigidnosti pokazati niži stepen opšteg mentalnog zdravlja (H1-e). Ovakav rezultat nije u skladu sa teorijskim postavkama Svitkevicheve (2022), prema kojima rigidnost može negativno uticati na različite aspekte mentalnog zdravlja. I Rozentel (2020) ukazuje na to da rigidnost može ometati fleksibilnost i adaptaciju, što negativno utiče na mentalno zdravlje. Grahovac (2020) navodi da rigidni obrasci mišljenja i ponašanja ograničavaju emocionalnu otpornost i otežavaju suočavanje sa životnim izazovima. Iako su mnogi autori i istraživanja ukazivali da rigidnost utiče negativno na mentalno zdravlje, rezultati našeg uzorka to nisu potvrdili. Mogući razlog ovakvih nalaza možemo pripisati jednoj od vrsta rigidnosti, a to je afektivna rigidnost, koja podrazumijeva da individua uvijek odgovara na isti način bez promjene emocija, istim odgovorom, bez obzira koja je situacija u pitanju. Kako se rigidna osoba čvrsto i dosljedno drži svojih krutih stavova, oni joj na takav način omogućavaju zaštitu od mnogih stresogenih faktora, a time i zaštitu od razvoja anksioznosti i depresije. Rigidnost kao osobina postaje sastavni dio osobe, čvrsto ukorijenjena u svakodnevno funkcionisanje, koje osobi omogućava održavanje dobrog opšteg mentalnog stanja.

Drugom opštom hipotezom ispitivali smo razlike između ispitanika različitih sociodemografskih obilježja u odnosu na nivo izraženosti rigidnosti, nivoa perfekcionizma i nivoa

opšteg mentalnog zdravlja na našem uzorku. Očekivanje da će žene postizati veće skorove na perfekcionizmu i anksioznosti, a muškarci veće skorove na rigidnosti (H2-a) temeljilo se na istraživanju Bandelowa i Michaelisa (2015) o razlikama između polova. U dostupnoj literaturi ima istraživanja koja potenciraju prisustvo rodni razlika u izraženosti perfekcionizma i anksioznosti (Flett i saradnici, 2022), a mogu se naći i objašnjenja da rigidni obrasci mišljenja i ponašanja mogu biti izraženiji kod muškaraca zbog društvenih normi i očekivanja (Svitkevich, 2022). Kako je u sprovedenom istraživanju dobijeno da muškarci imaju više skorove i na rigidnosti i na perfekcionizmu, dok na drugim konceptima razlika nije dobijena, može se reći da dobijeni nalazi istraživanja djelimično podržavaju hipotezu H2-a. Na našim prostorima i dalje važi mišljenje da muškarac treba biti snažniji, bolji, vođa i lider, što se može povezati sa nalazima o većem perfekcionizmu zbog želje da ispuni sva očekivanja.

Podhipotezom H2-b izraženo je očekivanje da mlađi ispitanici imaju veće skorove na perfekcionizmu, dok stariji ispitanici imaju veće skorove na rigidnosti. U našem istraživanju dobijeni rezultati referišu da stariji ispitanici pokazuju veći nivo rigidnosti, što je u skladu sa teorijskim stavovima Grahovac (2020), prema kojima rigidnost može rasti s godinama kao mehanizam za očuvanje stabilnosti. Slične nalaze pruža i istraživanje Browna i saradnika (2018), koji ukazuju na to da rigidnost može postati izraženija sa godinama zbog većeg fokusa na stabilnost i sigurnost. S druge strane veza sa perfekcionizmom, koja je pretpostavljena, da mlađi pojedinci često težnju za savršenstvom koriste kao strategiju za postizanje visokih standarda i ličnog razvoja (Flett i Hewitt, 1991) nije dobijena. Dakle, dobijeni rezultati djelimično idu u prilog hipotezi H2-b i djelimično je potvrđuju. Očekivano je da kako godine prolaze, osoba na osnovu životnog iskustva ima sve stabilnije stavove, formiran vlastiti kriteriji na svim aspektima života, te teže podliježe bilo kakvim promjenama koje nisu u skladu sa njenim razmišljanjima i odlukama.

Naša pretpostavka da će ispitanici nižeg socioekonomskog statusa i iz ruralnih područja, imati niži stepen opšteg mentalnog zdravlja (H2-c) je djelimično podržana rezultatima koji pokazuju niže nivoe opšteg mentalnog zdravlja kod ispitanika nižeg socioekonomskog statusa i iz ruralnih područja. Ovi nalazi se donekle slažu s tvrdnjama Schmidta i saradnika (1954), koji navode da osobe s manje resursa za suočavanje sa stresom često imaju slabije mentalno zdravlje. Takođe, Subotić (2014) naglašava važnost socioekonomskog konteksta u razvoju i očuvanju mentalnog zdravlja, što je potvrđeno u ovom istraživanju. Jones i Smith (2017), takođe, ističu da manji pristup resursima i socijalna podrška mogu doprinijeti lošijem mentalnom zdravlju kod osoba sa nižim socioekonomskim statusom. Hipoteza H2-c je djelimično potvrđena, jer je analiza pokazala da najniži nivo opšteg mentalnog zdravlja imaju stanovnici predgrađa. Dobijeno se u narednim istraživanjima može detaljnije ispitati provjerom socioekonomskog statusa ljudi iz predgrađa, odnosno provjerom da li je do lošeg opšteg mentalnog zdravlja došlo zbog problema sa egzistencijom (jer su prisiljeni da budu usmjereni na grad, a nemaju dovoljno resursa za hranu) ili stres dolazi od nekih „preduzetničkih“ i poslovnih problema ljudi na visokim pozicijama, jer je u posljednje vrijeme poznato da takvi ljudi na periferiji traže mir.

Očekivanje da prvorodeni ispitanici imaju veće skorove na perfekcionizmu u odnosu na ostale ispitanike (H2-d) nije potvrđeno. U raznim teorijskim konceptima naglašavaju se uloge roditeljskih očekivanja i pritiska na prvorodenu djecu (Sulloway, 1996; Slade & Owens, 1998). Sulloway (1996) je smatrao da redoslijed rođenja može doprinijeti različitom razvoju osobina ličnosti, uključujući rigidnost i perfekcionizam, što ipak na ovom uzorku nije potvrđeno. Na osnovu ovih nalaza, moguće je da prvorodena djeca ipak nisu pod tako velikim pritiskom ili da je za njihovo potvrđivanje potreban nešto veći uzorak ispitanika.

Ograničenja rada

Iako je istraživanje sprovedeno organizovano, planski i odgovorno, u obzir se trebaju uzeti brojna ograničenja koja su mogla da imaju uticaj na konačne rezultate. Jedna od tih ograničenja jeste veličina uzorka (212 ispitanika), pa bi za neka naredna istraživanja bilo poželjnije da se veličina uzorka poveća, kako bi i rezultati bili pouzdaniji. Naredno ograničenje bi bilo način popunjavanja upitnika, tj. direktno i indirektno (putem društvenih mreža). Kod oba načina popunjavanja neki ispitanici su bili nepovjerljivi i nesigurni da je sve potpuno anonimno, pa

vjerovatno da nisu bili potpuno iskreni u davanju odgovora. Dodatno kod online popunjavanja je to što ne znamo da li su svi ispitanici shvatili baš svaku uputu i pitanje, te da na taj način nisu davali pogrešne odgovore. Zatim, ono što treba uzeti u obzir, jeste samoprocjena, što govori o apsolutnom prisustvu subjektivnosti. Poznato je da nismo isti u svojim očima kao u tuđim, te da samoprocjenom ljudi najčešće daju društveno poželjne i prihvatljive odgovore, kako bi sebe predstavili u najljepšem izdanju. Svi ovi razlozi su mogli jednim dijelom da utiču na metodološki dio istraživanja i konačni rezultat.

ZAKLJUČCI

Sprovedeno istraživanje ne potvrđuje značajnu povezanost između rigidnosti, perfekcionizma i različitih aspekata mentalnog zdravlja, što nije u skladu s prethodnim teorijskim postavkama i istraživanjima. Rezultati ne ukazuju na to da rigidni obrasci mišljenja mogu povećati rizik od razvoja negativnih mentalnih stanja, kao što su depresija, anksioznost i stres. Rigidnost se, na ovom uzorku, nije pokazala kao faktor koji otežava fleksibilno suočavanje s promjenama i prilagođavanjem. Ali, nalaz o postojanju razlika među sociodemografskim grupama naglašava potrebu za razumijevanjem socijalnih i kulturnih faktora koji utiču na mentalno zdravlje.

Istraživanje je sprovedeno na uzorku koji može biti ograničen u smislu reprezentativnosti, jer se rezultati možda ne mogu generalizovati na širu populaciju. Do konačnih podataka smo došli putem samoprocjene ispitanika, a znamo da samoprocjena može unijeti subjektivnost u rezultate, što može uticati na tačnost mjerenja i biti još jedna ograničenost rada. Pored toga, dodatno ograničenje je korišćenje transfezalne metodologije, koja ne omogućava zaključke o uzročno-posljedičnim odnosima. Rezultati se takođe ne mogu generalizovati na šire populacije bez opreznosti. Longitudinalne studije bi mogle omogućiti bolju procjenu uzročno-posljedičnih veza između rigidnosti, perfekcionizma i mentalnog zdravlja. Takođe, buduća istraživanja bi trebala uključiti veći uzorak i razmatranje dodatnih faktora, poput životnih stresora, društvene podrške i kulturnih normi.

Ovi rezultati pružaju važne implikacije za razvoj psihoterapijskih strategija koje bi mogle biti usmjerene na smanjenje rigidnosti i poboljšanje mentalnog zdravlja u različitim sociokulturološkim okvirima, te pružaju smjernice za prilagođavanje intervencija specifičnim potrebama različitih sociodemografskih grupa.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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THE RELATIONSHIP BETWEEN RIGIDITY, PERFECTIONISM AND MENTAL HEALTH

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ABSTRACT

Rigidity is one of the oldest psychological constructs to which, today, in the literature, traits such as egocentrism, authoritarianism, obsessiveness, inflexibility, and similar are associated. From the psychiatry's point of view, a rigid person is not a sick person, but a normal, healthy person with a special personality trait. The aim of this study was to determine whether rigidity as a personality trait is statistically significantly associated with perfectionism and the general state of mental health, measured through the parameters of stress, anxiety, and depression levels. The sample consisted of 212 respondents, of whom 110 were female and 102 were male. The following measuring instruments were used: Structured questionnaire for sociodemographic data (constructed for the needs of this study), Brexin's rigidity scale, Burns' perfectionism scale, Mental Health Inventory (MHI-5), Depression, Anxiety, and Stress Scale (DASS).

The research results did not reveal a significant connection between rigidity and perfectionism and different aspects of mental health, which is not in accordance with the presented theoretical assumptions and previous researches. However, the obtained results showed that there is a difference between the examined concepts in relation to gender, whereby men show a significantly higher level of rigidity ($p=.01$) and perfectionism ($p=.05$) compared to women. Statistically significant differences were found between the level of rigidity and the variable "age" ($p=.05$): older respondents in the sample are more rigid in their behavior compared to younger respondents. Also, the research showed that respondents from the suburbs, as a place of residence, produce a higher level of depression and stress compared to respondents from the countryside and the city, while no statistically significant differences were found in relation to the variable "stress".

Keywords: rigidity, perfectionism, mental health.

THE VALUES AND ATTITUDES AS DRIVERS OF ORGANIC FOOD PURCHASE

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ABSTRACT

Values are one of the fundamental concepts that explain the human behavior, both individually and socially (Slijepčević & Matanović, 2015). Attitudes and values can greatly influence and guide our decisions and behavior. The aim of this research was to determine how attitudes and values about organic food can influence the decision to purchase it. Basis for this research was The Schwartz Theory of Basic Values and The Theory of Planned Behavior. In the first part, the questionnaire comprises 20 variables (Krystallis et al., 2008). It is divided into the three sections: the list of 17 Portrait Value Questionnaire (PVQ), organic food shopping behavior, and list of nine organic food-related consumer beliefs. For the second part of this research the questionnaire is used to determine attitude, subjective norm, perceived behavioral control, perceived barriers, self-efficacy, past behavior and intention (Chan et al., 2016). The research involved 352 respondents, of whom 232 were women and 120 were men. The results showed a large number of statistically significant correlations between the variables used. The most significant correlation is related to the decision to buy organic food, which is more likely for respondents with higher scores on the Benevolence, Universalism, Self-direction and Security subscales.

Keywords: organic food, values, attitudes, the Schwartz theory.

INTRODUCTION

Values are one of the fundamental concepts that explain the human behavior, both individually and socially (Slijepčević & Matanović, 2015). They are generally understood as extremely stable constructs that are not easily changed, even if considerable effort is invested. As a result, values can serve as better predictors of behaviour over extended periods of time (Krystallis et al., 2008) and can provide guidelines to organic food producers and traders by predicting consumer behaviour.

Based on several decades of psychology research Schwartz proposed 10 basic motivational values that incorporate virtually all specific values from different cultures around the world: benevolence, universalism, self-direction, stimulation, hedonism, achievement, power, security, conformity and tradition (Schwartz, 2004). Benevolence refers to the preserving and enhancing the welfare of those with whom the person is in frequent contact; Universalism implies understanding, appreciation, tolerance and protection for the well-being of all; Self-direction refers to independency; Stimulation to excitement, novelty and challenges in life; Hedonism is defined as personal pleasure; Achievement refers to a personal success through the demonstration of competence; Power refers to the social status and prestige, control or dominance over people and resources; Security is identified as safety, harmony and stability; Conformity is defined as restraint of actions that may upset or harm others and Tradition refers to the respect, devotion and acceptance of customs and ideas that are part of an individual's cultural or religious heritage (Aertsens et al., 2009; Krystallis et al., 2008). These values are organized onto a motivational continuum that reflects the dynamic interplay between self-enhancement and self-transcendence, as

well as openness to change versus conversations. Each of them may have influence on consumer decisions.

Recent research proposes that the relations of personal values to behaviour are stronger at higher value importance and weaker at lower levels (J. A. Lee et al., 2021). The Theory of planned behaviour has been widely applied in research with aim to understand individual behaviour, including organic consumers (Zagata, 2012).

Organic food consumption has been steadily increasing over past two decades, largely driven by rising consumer concerns about health, environmental sustainability and food safety (van den Berge et al., 2025). Consequently, understanding the structure and influence of personal values becomes a crucial aspect of exploring consumer behaviour in the organic food sector.

MATERIAL AND METHODS OF WORK

The aim of this research was to determine how the attitudes and values as the basis of human behavior can influence their decision to buy organic food. The research is based on The Schwartz Theory of Basic Values and The Theory of Planned Behavior. For that purpose, the questionnaire was designed (Chan et al., 2016; Krystallis et al., 2008). It consists from four parts where first part examines values, second attitudes, beliefs, subjective norms, behavioral control, perceived barriers and self-efficacy, third part investigates organic food purchase frequencies and intentions and fourth part is giving socio-demographic profile of respondents.

Table 1. Descriptive statistics in percentages.

Gender	Household				5 y kids				6-12 y kids				13-18 y kids				Residence	Salary	Edu.	Years
M	65,9	0	5,1	0	94,0	0	92,9	0	90,6	Up to 10,000	13,9	< avg.	11,4	P	2,8	<18	2,0			
F	34,1	1	18,8	1	4,5	1	0,5	1	8,2	10.001-50.000	59,7	Avg.	71,6	H	53,7	19-25	21,3			
		2	21,3	2	0,6	2	0,3	2	0,6	50.001-100K	14,8	> avg.	17,0	U	42,0	26-35	21,6			
		3	33,5	3	0,9	3	,3	3	0,6	100K +	11,6			hD	1,4	36-45	26,4			
		4	21,3													46-55	19,0			
																>56	9,7			

The resreach involved 352 respondents, of whom 232 were women (65,9 %) and 120 were men (34,1%). The majority of respodents 95,5% are from Republika Srpska, 59,7% of them live in small towns with 10.000 to 50.000 people and 71,6% states their monthly income is average. The age groups are scattered, but 48% of respodents belongs to age gruops between 36-45 years (26,3%) and 26-35 years (26,3%). The majority of respodents 95,7% have finished secondary school (42%) and university degree (53,7%).

The Schwartz Theory of Basic Values

Until recently, all studies that support The Values theory employed a single measurement instrument, the Schwartz Value Survey (SVS). A more concrete typology, however, the Portrait Value Questionnaire (PVQ) is designed to measure the same 10 value constructs, and the questions are adapted to the aim of this research (Krystallis et al., 2008). In this research PVQ will be used as a more suitable instrument because the SVS demands a high level of abstract thought and presents value concepts outside any specific context (Schwartz, 2004).

The first section contains adapted 17-item PVQ based inventory that includes consumer values related to organic food, according to the survey done using a nationally representative sample of 1043 Greek consumers (Krystallis et al., 2008). The questionnaire will cover 7 out of 10 domains: benevolence, universalism, self-direction, stimulation, hedonism, achievement and security. These values domain cover completely the self-transcendence and openness to change and partially the self-enhancement and conservation value dimensions. From the three domains not covered, tradition and power are found the least important in most PVQ applications around the world. A respondent may score the answers on 6-points Likert scale from 1 (very much like me) to 6 (not like me at all).

For research based on The Schwartz Theory of Basic Values, following hypothesis are set:

- H1) There is a positive relationship between benevolence value and the intention to purchase organic food;
- H2) There is a positive relationship between universalism value and the intention to purchase organic food;
- H3) There is a positive relationship between self-direction value and the intention to purchase organic food;
- H4) There is a positive relationship between stimulation value and the intention to purchase organic food;
- H5) There is a positive relationship between hedonism value and the intention to purchase organic food;
- H6) There is a positive relationship between achievement value and the intention to purchase organic food;
- H7) There is a positive relationship between security value and the intention to purchase organic food.

The Theory of Planned Behavior

The second part of this research will examine relations between attitude, subjective norm, perceived behavioral control, perceived barriers, self-efficacy, and past behavior on one side and intention to organic food purchase and consumption on the other side (Chan et al., 2016). Each construct is operationalized using items adapted from validated instruments, as described below:

Attitude towards healthy eating was measured by asking participants to rate on a 5-point semantic differential scale for six pairs of evaluative adjectives to describe attitudes to organic food from 1 (very) to 5 (not at all) – question 20,

Beliefs towards organic food benefits was measured by asking participants to rate on a 7-point semantic differential scale from 1 (I strongly believe) to 7 (I strongly do not believe). The list includes five positive beliefs (organics are free from chemicals, have better taste, are better for the environment, are healthier and are more natural) and four negative beliefs (organics are more expensive, keep fresh less, are less attractive and are not really organics) (Krystallis et al., 2008). – question 21,

Subjective norms, defined as suggestion for healthy diet, was measured by asking participants to indicate how often they receive such suggestions from six different sources, using a 5-point scale ranging from 1 (very often) to 5 (never): The sources included: friends, family, TV programs, magazines and newspaper, the internet, and government promotional messages - question 22,

For perceived behavioural control, participants were asked to rate three statements to what extent they have control on healthy eating by rating the truth to statements on 5-point scale

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(1=definitely yes, 5=definitely no). The statements are: I will try very hard to eat healthier, I am disciplined enough to eat healthier, I have enough time to eat healthier – question 23,

Perceived barriers – reasons for unhealthy diet were rated on 5-point scale where 1 (strongly agree) and 5 (strongly no) – question 24,

Self-efficacy in context of decisions for future organic food consumption was measured by asking participants to rate four statements on a 5-point scale where 1 (strongly yes) and 5 (strongly no) – question 25,

The following questions were designed to directly examine the previously defined hypotheses are:

- past eating behaviour was measured by asking participants how often they consumed organic food in the previous month, using a 5-point scale ranging from 1 (very often) to 5 (never) – question 26.

Healthy eating intention was measured with two questions:

- Do you intend to consume organic food next week?
- How likely is it that you will consume organic food next week?

Both questions were rated on 5-point scale where 1 (definitely yes) and 5 (definitely no) - question 27 and 28.

Before applying statistical techniques, the normality of data distribution was tested using Kolmogorov-Smirnova and Shapiro-Wilk tests. As both tests indicated significant deviations from normality ($p < 0,05$), non-parametric methods were applied in further analysis. To examine the relations between the variables, the Spearman's rank correlation coefficient was used, while Kruskal-Wallis's test was applied to assess group differences. In addition to the research, the correlations between socio-demographic variables and value/attitudes are examined.

RESULTS AND DISCUSSION

Kolmogorov-Smirnova and Shapiro-Wilk tests for checking the distribution of data show that the data are unevenly distributed, and for this reason non-parametric tests are used in further processing (Table 1).

To determine whether there is a correlation between the scales used, as well as which type of correlation is dominant, the Spearman rho correlation coefficient was used (Tables 2 and 3).

In Table 2, we can see a larger measurement of the association between the sociodemographic variables and the scales used in the research. The coefficients that show statistical significance is the positive correlation coefficient between gender and benevolence, which indicates that male respondents as organic-related consumers show a higher score than female respondents on this subscale ($Rho = 0,14$, $p = 0,01$). The male gender also has higher scores on subjective norms, meaning they tend to be more influenced by people and the environment suggesting them they should have healthier diet ($Rho = 0,16$, $p = 0,00$).

Significant negative correlations were obtained between the benevolence and achievement subscales compared to the variable on the number of children under 5 years old ($Rho = -0,19$, $p = 0,00$; $Rho = -0,20$, $p = 0,00$) and between the benevolence and beliefs subscale compared to the variable on the size of the place of residence ($Rho = -0,15$, $p = 0,01$; $Rho = -0,18$, $p = 0,00$) This leads to conclusion that the respondents with children under 5 years old and those who live in a smaller cities have a lower score on the benevolence subscale ($Rho = -0,19$, $p = 0,00$; $Rho = -0,15$, $p = 0,01$). Previous research showed that consumers from rural areas have less interest in buying organic milk and milk products than consumers from urban area (Čolović & Mitić, 2023). Families with more children under 5 years of age also tend to have lower scores on the achievement scale ($Rho = -0,204$, $p = 0,00$), and those with children between 6 and 12 years have more negative beliefs towards organic food ($Rho = -0,176$, $p = 0,00$).

Table 1. Tests of normality.

	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PVQ Benevolence	,165	352	,000	,846	352	,000
PVQ Universalism	,213	352	,000	,773	352	,000
PVQ Self direction	,243	352	,000	,714	352	,000
PVQ Stimulation	,113	352	,000	,954	352	,000
PVQ Hedonism	,151	352	,000	,885	352	,000
PVQ Achievement	,150	352	,000	,921	352	,000
PVQ Security	,272	352	,000	,704	352	,000
Attitude total	,178	352	,000	,848	352	,000
Beliefs total	,106	352	,000	,858	352	,000
Suggestion total	,087	352	,000	,979	352	,000
Truth fo statements total	,102	352	,000	,943	352	,000
Reasons for unhealthy diet total	,067	352	,001	,986	352	,002
Food decision total	,071	352	,000	,967	352	,000

The results showed negative and significant relation between education and total suggestion ($Rho=-0,149$, $p=0,00$) meaning that these respondents are less likely to be influenced by the environment suggesting to them to eat healthier.

Older respondents have significant and positive higher scores on the stimulation, hedonism and achievement subscales ($Rho=0,29$, $p=0,00$; $Rho=0,24$, $p=0,00$; $Rho=0,18$, $p=0,00$) meaning that older consumers (age between 36-45 years and more) are more prone to challenges, personal pleasure and achievements. Younger respondents have more negative beliefs about the quality of organic food what is in the line with previous research (Sudarević & Radojević, 2018), but they are also less susceptible to being influenced by suggestions from media, family and friends ($Rho=-0,26$, $p=0,00$; $Rho=-0,20$, $p=0,00$). The importance of trust as the most crucial factor affecting the purchase behaviour of young people is investigated in Vietnam (Nguyen & D. Vo, 2023). Younger respondents are less inclined to determine the reason for not eating healthy ($Rho=-0,20$, $p=0,00$).

Other socio-demographic variables like salary/income and size of household did not show significancy.

The correlation coefficients between the PVQ scales and the scales on the overall attitude, beliefs, suggestibility, truth of the proposed statements, reasons for unhealthy eating and the final decision to buy organic food are shown in Table 3.

Overall attitude towards organic food is significantly and positively correlated with benevolence and universalism, meaning that respondents with higher scores on these two PVQ subscales who care for welfare of close people and environment, have positive attitude towards organic food ($Rho=0,23$, $p=0,00$; $Rho=0,32$, $p=0,00$). These respondents find organic food interesting, useful, pleasant, good and valuable. Their perceived behavioral control is also positive and significant ($Rho=0,15$, $p=0,01$; $Rho=0,14$, $p=0,01$) indicating their will and discipline towards the healthy diet and they have positive intentions to buy and consume organic food in the near future ($Rho=0,22$, $p=0,00$; $Rho=0,27$ $p=0,00$). These findings are in the line with previous research papers that confirms that consumers with mentioned values and attitude towards organic food are engaged in organic food consumption (Chan et al., 2016; Galić, 2022; Grubor & Djokic, 2016; Valero-Gil et al., 2023). While some research shows a general lack of concern about food production effects on the environment and animal welfare (Ali, 2021; Shashi et al., 2016), many surveys put positively related attitudes towards environment care (Kushwah et al., 2019; Santiago et al., 2025) and food safety (Fleseriu et al., 2020) as a significant motivator behind organic food purchase.

Higher scores on the self-direction subscale indicate significant and positive intention to buy and consume organic food in the near future ($Rho=0,12$, $p=0,02$). These respondents highly value independency in setting their goals and making decisions.

Table 2. Correlations.

		Gender	Household	5 y kids	6-12 y kids	13-18 y kids	residence	RS	Salary	Education	Age
PVQ_ Benevolence	Rho	,144**	-,025	-,194**	-,006	-,028	-,150**	,009	-,028	-,041	,054
	p	,007	,635	,000	,908	,600	,005	,860	,600	,445	,312
PVQ_ Universalism	Rho	,123*	,070	-,092	,051	,015	-,133*	-,014	-,035	-,025	-,019
	p	,021	,190	,084	,340	,785	,013	,788	,518	,637	,728
PVQ_ Self_direction	Rho	,028	,110*	-,053	-,008	-,026	-,091	,002	-,056	,011	,029
	p	,598	,039	,323	,886	,625	,088	,976	,293	,840	,587
PVQ_ Stimulation	Rho	-,005	-,009	-,080	,015	-,089	-,102	,012	-,116*	,009	,289**
	p	,925	,872	,136	,780	,097	,057	,815	,029	,868	,000
PVQ_ Hedonism	Rho	,024	-,036	-,065	-,022	-,117*	-,061	,085	-,078	,083	,235**
	p	,659	,497	,223	,685	,029	,256	,111	,145	,122	,000
PVQ_ Achievement	Rho	,063	-,005	-,204**	-,025	-,010	-,092	,070	-,122*	-,037	,176**
	p	,238	,921	,000	,643	,853	,086	,189	,022	,491	,001
PVQ_ Security	Rho	,070	,097	-,004	,094	-,034	-,026	,054	,006	,058	-,017
	p	,191	,068	,937	,077	,530	,632	,311	,910	,277	,745
Attitude total	Rho	,112*	-,032	-,112*	,003	-,015	-,116*	-,018	-,041	-,060	-,080
	p	,036	,546	,035	,960	,773	,030	,734	,443	,258	,134
Beliefs total	Rho	-,010	-,051	-,096	-,176**	,036	-,178**	-,022	-,075	-,131*	-,256**
	p	,848	,341	,071	,001	,498	,001	,686	,162	,014	,000
Suggestion total	Rho	,165**	-,062	-,020	-,091	,021	-,098	-,079	-,019	-,149**	-,197**
	p	,002	,245	,705	,087	,697	,066	,137	,724	,005	,000
Truth fo statements total	Rho	-,017	-,038	,031	,016	-,038	-,127*	-,093	-,051	-,096	,040
	p	,748	,473	,562	,762	,473	,018	,081	,341	,073	,455
Reasons for unhealthy diet total	Rho	,029	,101	-,046	,002	,048	-,045	,033	,100	,035	-,198**
	p	,583	,057	,393	,964	,372	,401	,543	,062	,509	,000
Food decision total	Rho	,027	-,013	-,053	-,024	-,101	-,136*	-,069	-,057	-,052	-,018
	p	,611	,815	,321	,651	,059	,011	,196	,287	,327	,741

Table 3. Correlations.

		PVQ_ Benevolence	PVQ_ Universalism	PVQ_ Self_direction	PVQ_ Stimulation	PVQ_ Hedonism	PVQ_ Achievement	PVQ_ Security
Attitude total	Rho	,235	,318	,120	,018	,063	,124	,108
	p	,000	,000	,024	,732	,242	,020	,042
Beliefs total	Rho	,062	,017	-,035	-,057	-,043	,062	-,035
	p	,242	,755	,513	,288	,425	,249	,517
Suggestion total	Rho	-,064	-,015	-,098	-,192	-,135	-,050	-,052
	p	,228	,784	,065	,000	,011	,349	,329
Truth fo statements total	Rho	,146	,143	,046	,129	,072	,100	,181
	p	,006	,007	,385	,015	,178	,060	,001
Reasons for unhealthy diet total	Rho	-,088	-,109	-,079	-,067	-,040	,022	-,020
	p	,100	,041	,139	,208	,450	,682	,704
Food decision total	Rho	,220	,274	,124	,109	,113	,100	,200
	p	,000	,000	,020	,040	,034	,062	,000

Respondents with a higher score on the stimulation subscale are less likely to be influenced by suggestions ($Rho=-0,19$, $p=0,00$). These consumers value excitement, novelty and challenges in life, but the results showed they are not inclined to listen an advice from others.

Respondents with higher scores on the Security subscale rate claims about organic food as accurate and they showed intention to purchase organic food in near future ($Rho=0,18$, $p=0,00$; $Rho=0,200$, $p=0,00$).

Higher scores on the Benevolence, Universalism, Self-direction and Security subscales indicate positive intention to buy and consume organic food in the near future ($Rho=0,22$, $p=0,00$; $Rho=0,27$, $p=0,00$; $Rho=0,12$, $p=0,02$; $Rho=0,20$, $p=0,00$). The hypothesis H1, H2, H3 and H7 are confirmed:

Hypothesis H1: There is a positive relationship between benevolence value and the intention to purchase organic food is confirmed;

Hypothesis H2: There is a positive relationship between universalism value and the intention to purchase organic food is confirmed;

Hypothesis H3: There is a positive relationship between self-direction value and the intention to purchase organic food is confirmed;

Hypothesis H7: There is a positive relationship between security value and the intention to purchase organic food is confirmed.

The values benevolence and universalism are very often related with intention to purchase and consume organic food (Krystallis et al., 2008; H. J. Lee, 2019; Leyva-hernández et al., 2025)

The results showed that other values did not show significance, therefor the hypothesis H4, H5 and H6 are rejected:

Hypothesis H4: There is a positive relationship between stimulation value and the intention to purchase organic food is rejected;

Hypothesis H5: There is a positive relationship between hedonism value and the intention to purchase organic food is rejected;

Hypothesis H6: There is a positive relationship between achievement value and the intention to purchase organic food is rejected.

In following research, the non-parametric Kruskal-Wallis test was used to compare differences between groups. The test revealed statistically significant differences in the level of overall attitude towards organic food in relation to the representation of the benevolence and universalism subscales (c^2 (5, $n=352$) = 25,45, $p=0,00$; c^2 (5, $n=352$) = 38,93, $p=0,00$). The parameter values show that the highest values on the attitude total variable have those respondents who are in response group number 2 (agree) on the benevolence subscale, as well as those respondents who are in response group number 3 (more agree than disagree) on the universalism subscale (Table 4).

Table 4. Kruskal-Wallis test for Attitude total and PVQ subscales Benevolence and Universalism.

	PVQ_Benevolence				PVQ_Universalism			
	Mean Rank	Median	Chi-square	p	Mean Rank	Median	Chi-square	p
Attitude total	1 150,63	7	25,448	0,000	153,56	8	26,234	0,000
	2 206,28	10			208,66	10		
	3 198,75	9			252,73	15		
	4 200,21	9			192,58	8		
	5 195,75	8			136,28	3		
	6 135,00	7			202,88	5		

Kruskal-Wallis test also revealed statistically significant differences in the level of overall Suggestion in relation to the PVQ Stimulation subscale (c^2 (5, $n=352$) = 26,39, $p=0,00$). The parameter values show that the highest values on the suggestion total variable have those

respondents who are in response group number 1 (completely agree) on the Stimulation subscale (Table 5).

There is also one statistically significant difference in the level of overall Truth for statements in relation to the PVQ stimulation subscale benevolence (c^2 (5, $n=352$) = 11,73, $p=0,04$), while no statistically significant difference was found for the subscales universalism and security (Table 6a, 6b). The parameter values show that the highest values on the truth for statements variable have those respondents who are in response group number 3 (more agree than disagree) on the benevolence subscale (Table 6a).

Table 5. Kruskal-Wallis test for Suggestion total and PVQ subscale Stimulation.

		PVQ_ Stimulation			
		Mean Rank	Median	Chi-square	p
Suggestion total	1	212,66	19	26,388	0,000
	2	189,19	18		
	3	148,70	16		
	4	145,24	15		
	5	202,93	17		
	6	188,50	18		

Table 6a. Kruskal-Wallis test for Truth for statements and PVQ subscales Benevolence, Universalism and Security.

		PVQ_ Benevolence			PVQ_ Universalism			
		Mean Rank	Median	Chi-square	Mean Rank	Median	Chi-square	p
Truth for statements	1	161,33	6	11,731	166,69	7	9,720	0,084
	2	189,41	7		200,73	7		
	3	207,79	8		198,10	7		
	4	189,29	6		178,08	7		
	5	170,88	6		133,28	5		
	6	162,60	6		163,63	6		

Table 6b. Kruskal-Wallis test for Truth for statements and PVQ subscales Benevolence, Universalism and Security.

		PVQ_ Security			
		Mean Rank	Median	Chi-square	p
Truth for statements	1	165,66	6	9,749	,083
	2	196,32	7		
	3	230,76	8		
	4	223,89	7		
	5	119,39	6		
	6	199,21	6		

Kruskal-Wallis test also revealed statistically significant differences in the level of variable food decision total in relation to the PVQ subscales stimulation subscale benevolence, universalism and security (c^2 (5, $n=352$) = 27,54, $p=0,00$; c^2 (5, $n=352$) = 21,41, $p=0,00$; c^2 (5, $n=352$) = 14,95, $p=0,01$), while no statistically significant difference was found for the subscale self-direction (Table 7a, 7b).

The parameter values show that the highest values on the food decision total variable have those respondents who are in response group number 4 (disagree more than agree) on the benevolence and universalism subscales (Table 7a). In Table 7b, it is shown that respondents who are in response group number 3 (more agree than disagree) on the security subscale also have highest values on the food decision total variable.

Table 7a. Kruskal-Wallis test for Food decision total and PVQ subscales Benevolence, Universalism, Self – direction and Security.

		PVQ_Benevolence				PVQ_Universalism			
		Mean Rank	Median	Chi-square	p	Mean Rank	Median	Chi-square	p
Food decision total	1	151,72	15	27,543	0,000	156,88	16	21,412	0,001
	2	202,34	18			200,79	18		
	3	185,68	18			207,93	18		
	4	226,00	19			230,23	19		
	5	223,00	17			224,78	18		
	6	144,60	16			199,63	17		

Table 7b. Kruskal-Wallis test for Food decision total and PVQ subscales Benevolence, Universalism, Self – direction and Security.

		PVQ_Self-direction				PVQ_Security			
		Mean Rank	Median	Chi-square	p	Mean Rank	Median	Chi-square	p
Food decision total	1	169,05	16	8,205	0,145	166,40	16	14,980	0,010
	2	190,01	18			189,63	17		
	3	177,66	15			202,68	18		
	4	192,38	18			195,78	16		
	5	154,83	15			229,36	19		
	6	203,00	17			167,43	17		

CONCLUSIONS

The results of this study provide valuable insights into the role of personal values and socio-demographic factors in shaping consumer attitudes and intentions toward organic food consumption. The Spearman's Rho correlation analysis revealed significant relation between specific value orientation (measured by PVQ subscales) and attitudes, beliefs and intentions regarding organic food.

The values benevolence, universalism, self-direction and security were positively and significantly associated with intention to purchase and consume organic food. Respondents who highly value welfare of others, environmental protection, independent thinking and safety show stronger positive attitudes and intentions. These findings support Hypothesis H1, H2, H3 and H7. Kruskal-Walli's test confirmed significant differences in attitude and decision making toward organic food across different levels of value subscales, especially benevolence, universalism and security.

The values stimulation, hedonism and achievement did not show a significant effect on the intention to purchase organic food leading to rejection oy Hypothesis H4, H5 and H6.

Socio-demographic variables gender, age, education, presence of children in household and place of residence also have impact on organic food related consumer behavior.

Organic food consumers with strong environmental and security – oriented values tend to form favorable attitudes toward organic food; they perceive fewer barriers to consumption and are more likely to be regular organic food consumers. This research has limitation reflected in the sample size and the fact that data were collected via an online questionnaire, which may have introduced a sampling toward more educated respondents who regularly use computers and the internet.

These findings can guide marketers, managers and policy maker in designing targeted campaigns for organic food consumers. As no similar research has been conducted in the territory of Republika Srpska, this study may serve as a basis for all future research. Following research should be structured in the form that can deepen the understanding of tested relations and investigate casual links between attitudes and consumer behavior.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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POVEZANOST PERCIPIRANE SOCIJALNE PODRŠKE SA ŠKOLSKIM POSTIGNUĆEM UČENIKA SREDNJIH ŠKOLA

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SAŽETAK

Savremeno obrazovanje postavlja sve veće zahtjeve pred učenike, očekujući od njih ne samo usvajanje akademskog znanja već i razvoj različitih socijalnih i emocionalnih kompetencija koje doprinose njihovom školskom uspjehu. Brojna istraživanja ukazuju da faktori poput motivacije, radnih navika i intelektualnih sposobnosti nisu jedini prediktori školskog postignuća, već da značajnu ulogu igra i socijalna podrška koju učenici percipiraju iz različitih izvora – roditelja, vršnjaka i nastavnika. Pojedina istraživanja pokazuju da učenici koji dobijaju veću socijalnu podršku ostvaruju bolje rezultate u školi, imaju razvijenije strategije suočavanja sa akademskim izazovima i iskazuju veći nivo motivacije za učenje (npr. Tayfur & Sevim, 2016; Mackinnon, 2012; Jiahui, et al., 2023; Saeed et al., 2023; Ahmed et al., 2008). Iako postoji značajan broj studija koje istražuju ovu temu, konzistentnost rezultata varira. Cilj ovog rada je bio utvrditi da li postoji povezanost između percipirane socijalne podrške od strane roditelja, nastavnika, vršnjaka kao i ukupne percipirane socijalne podrške i školskog postignuća učenika srednjih škola Tuzlanskog kantona. U istraživanju su učestvovala 384 ispitanika (50,8% ženskih i 49,2% muških ispitanika), učenika četiri srednje škole sa prostora Tuzlanskog kantona. Podaci o varijablama ispitivanja prikupljeni su putem upitnika sociodemografskih podataka, konstruisanog posebno za potrebe ovog istraživanja, te Skale percipirane socijalne podrške (Dubow, Ullman, 1989), kojom se procjenjuje podrška od roditelja, nastavnika i vršnjaka. Uprkos očekivanju da će percipirana socijalna podrška od strane roditelja, nastavnika i vršnjaka imati značajnu povezanost sa školskim postignućem učenika srednjih škola, rezultati istraživanja nisu potvrdili postavljene hipoteze. Dobijene korelacije su niske i nisu ukazale na statistički značajnu povezanost nezavisnih varijabli sa zavisnom varijablom. Ovi nalazi sugerisu da buduća istraživanja, kada je u pitanju srednjoškolski uzrat, treba da razmatraju dodatne varijable koje mogu medijatorski ili moderatorski uticati na odnos između socijalne podrške i školskog postignuća, uključujući individualne razlike u učenju, motivaciju i karakteristike školskog sistema.

Cljučne riječi: percipirana socijalna podrška, školsko postignuće.

TEORIJSKI OKVIR

Najveći broj potreba čovjek može da zadovolji isključivo suživotom sa drugim ljudima, u grupi (Klarin, 2004), jer grupni život u kooperaciji omogućuje korist na osnovu podjele zajedničkih resursa, podjele poslova, rada, međusobne zaštite, ali uz to, kooperativni život u grupi omogućuje i podrazumijeva davanje udjela u troškovima na koje ljudi moraju da budu spremni da izdvoje, pružajući na taj način na raspolaganje resurse putem kojih se daje doprinos grupnim ishodima (Zvonarević, 1976). Ovo svakako ne znači da čovjek ne postoji i ne može da funkcioniše van društvenog konteksta, tj. da posjeduje samo socijalni identitet, već da bi ispunio svoje životne ciljeve i da bi sebi obezbijedio opstanak, čovjek teži da bude dio grupe, te da u suživotu sa drugim ljudima može zadovoljavati svoje fiziološke, socijalne, emocionalne i druge potrebe. Povrh svega, svaki pojedinac posjeduje lični identitet, što ga čini drugačijim od svih ostalih, pored toga što je već sličan, odnosno isti kao i svi drugi (Kluckhohn & Murray, 1948).

Koncept socijalne podrške

U literaturi postoji veliki broj definicija socijalne podrške. Socijalna podrška se definiše kao skup beneficija za individuu, koje proističu iz bliskih odnosa sa drugim ljudima i koje mu pomažu da se nosi sa kriznim i stresnim događajima u životu (Petz, 1992). Ujedno, ona predstavlja pomoć bližnjih osoba i/ili institucija raspoloživih u slučaju potrebe (Lacković-Grgin, 2000). Ova podrška uključuje pripadnost, poštovanje, brigu i ljubav, ali i zajedničke obaveze (Cobb, 1976, prema Lin, 1986). Prema Kalinu (1979, prema Zvizdić, 2015), socijalna podrška podrazumijeva interpersonalne transakcije koje sadrže osjećanja, afirmaciju i pomoć. Socijalna podrška se definiše i kao percipirana dostupnost drugih, prema kojima pojedinac gaji povjerenje, kojima vjeruje i koji čine da se on osjeća zbrinuto i vrijedan kao osoba (Mindful, 2008).

Socijalna podrška se može definisati kao odgovornost za tuđe potrebe, procjena tuđih osjećanja i postupaka i pružanje pomoći u prilagođenom suočavanju sa problemom (Citrona, 1996, prema Cunningham & Barbee, 2000). Sa druge strane, socijalna podrška se može definisati kao dostupnost osoba na koje se oslanjamo, koje nam daju do znanja da se brinu o nama i da im je stalo do nas (Živčić-Bećirević, 1996). Ona se temelji na psihološkoj usklađenosti i međusobnom empatijskom razumijevanju dvije ili više osoba (Badr i sar., 2001).

Prema Thoitsu (1986), termin socijalna podrška se odnosi na sva ona ponašanja i aktivnosti kojima članovi porodice, prijatelji, susjedi i drugi, koji su uključeni u socijalnu mrežu, pomažu pojedincu u slučaju potrebe. Preko socijalne podrške, pojedinac može mijenjati istovremeno i situaciju i njeno značenje, kao i svoju emocionalnu reakciju.

Rezimirajući sve ove informacije, definicije socijalne podrške, kako to navodi autor Reber (1995), većinom se mogu obuhvatiti jednom uopštenom definicijom, a to je da socijalna podrška predstavlja one forme podrške, obezbijedene od strane drugih pojedinaca i grupa, koje pomažu čovjeku da se bolje nosi sa životom.

Tipovi socijalne podrške

Sidney Cobb (1976, prema Havelka, 1997) ističe da socijalnu podršku treba shvatiti kao obavijest, gdje se pod pojmom obavijesti podrazumijeva svaki izvorni komunikacijski proces, odnosno informacija, spoznaja. Kroz ovaj proces, uz pomoć te informacije, čovjek se nastoji uvjeriti u to da je zaštićen i da je voljen, da je cijenjen, da se brinu o njemu i da je član specifične mreže komunikacija i uzajamnih obaveza. Spomenuti činioči određuju tzv. funkcionalnu vrijednost socijalne podrške, gdje se ona odvija na nekoliko paralelnih nivoa. Na temelju svojih studija, istraživači su utvrdili postojanje različitih tipova podrške, te su tako ukazali na postojanje pet kvalitativno različitih tipova socijalne podrške: 1. Instrumentalna podrška, 2. Informacijska podrška, 3. Podrška mreže (tj. podrška druženjem), 4. Emocionalna ili afektivna podrška, 5. Podrška samopoštovanju ili validacijska (potvrđujuća) podrška (prema Zvizdić, 2015).

1. Instrumentalna podrška se naziva i vidljivom/opipljivom podrškom i odnosi se na obezbjeđenje finansijske pomoći, materijalnih, kao i drugih potrebnih usluga (pomoć u kućnim poslovima, u poslu, briga o djeci, servisne usluge i sl.). Ova vrsta podrške može pomoći u redukovanju i u najvećem broju slučajeva nisu nezavisne iz razloga što je veoma vjerovatno da će oni pojedinci, koji imaju više socijalnih kontakata, ujedno imati i više pristupa instrumentalnoj pomoći i podršci samopotvrđivanju.

2. Informacijska podrška se naziva još i podrška putem savjetovanja, usmjerenja, sugestija, korisnih informacija i kognitivnog vodstva, a predstavlja pomoć u definisanju, razumijevanju i suočavanju sa događajima koji imaju konotaciju problematičnih. Ovaj tip podrške je kognitivni, podrazumijeva i davanje sugestija i povratnih informacija o napretku osobe i oblikovan je prema specifičnoj situaciji.

3. Podrška mreže, podrška druženjem, socijalno druženje ili pozitivna socijalna interakcija podrazumijeva provođenje vremena sa drugim ljudima u različitim aktivnostima, među kojima dominira odmor i rekreativne aktivnosti. Ovaj tip podrške omogućava osobi razvijanje osjećaja pripadnosti grupi. Aktivnosti vezane za ovaj tip podrške, a posebno provođenje vremena sa drugima tokom njih, mogu redukovati stres putem ispunjavanja potrebe za napretkom i kontaktom sa drugima, preko čega se pruža pomoć smanjenjem misli osobe (distrakcijom) od brige o

problemima, a osim toga omogućavaju pozitivna afektivna raspoloženja. Cobb (1976, prema Lin, 1986) smatra da ovaj tip podrške podrazumijeva pružanje smisla i usmjerenja pojedincu u društvu u kojem pripada. Kako se u okviru nivoa socijalnog druženja pojedinac upućuje na ona društva kojima na osnovu njegovih ličnih interesa i sklonosti pripada, ova podrška se još i zove potpora pripadnosti.

4. Emocionalna (afektivna) podrška je specifična za bliske socijalne odnose i uključuje pružanje brige, nježnosti, ljubavi, prihvatanja, solidarnosti, empatije, povjerenja, poštovanja, kao i pružanje osjećaja privrženosti i intimnosti i ekspresiju tuge. Kroz ovakav tip podrške, pojedincu se pruža osjećaj topline, sigurnosti, pripadnosti, utjehe i ugodnosti, kao i osjećaja da je voljen, ali i zbrinut, ukoliko je ova podrška pružena u vrijeme doživljavanja stresa. Ovaj tip podrške se smatra bezuslovnom i predstavlja najintimniju formu podrške koja može biti prisutna u socijalnim relacijama (Dalton, Elias & Wandersman, 2001).

5. Podrška samopoštovanju predstavlja onu informaciju putem koje individua doznaje da je prihvaćeno njeno socijalno ja, kao i njena jedinstvenost. Samopoštovanje se povećava kroz davanje informacije osobi da je priznata na osnovu vlastite vrijednosti i iskustava i da je prihvaćen bez obzira na mogućnosti pravljenja ličnih pogreški. Ovakva vrsta podrške se naziva i *emocionalna podrška*, bliska podrška i ekspresivna podrška i ona se nalazi u osnovi bliskih odnosa, a zadovoljava jednu od važnijih ljudskih potreba - potrebu za socijalnim interakcijama.

Izvori socijalne podrške

Postoje brojni izvori beneficija koji se mogu identifikovati kao socijalna podrška pojedincu. Socijalna podrška je blisko povezana sa konceptom socijalne mreže ili vezom sa porodicom, prijateljima i drugim značajnim osobama iz društvenog kruga pojedinca (komšije, kolege, vršnjaci) (Vrućinić, 2012). Pojedini autori naglašavaju izuzetnu važnost socijalne podrške unutar porodice, te stoga govore o socijalnoj podršci unutar porodice i izvan nje. Kada se govori o socijalnoj podršci za djecu i mlade, autori (Vizek-Vidović, 1994, prema Ajduković, 1995) navode porodicu, školu i vršnjake kao značajne izvore socijalne podrške.

Uloga socijalne podrške od strane porodice/roditelja, vrlo je bitna za normalan rast i razvoj djece (Garmezy, 1991). Porodica, sama po sebi, predstavlja jedan dinamički sistem, koji se tokom vremena razvija i kojem svaki član djeluje na druge članove. Kao okruženje pružanja i primanja socijalne podrške, porodica je mjesto međusobne emocionalne bliskosti, komunikacije, obostrane podrške, mjesto za rješavanje problema, te rasta i razvoja kroz brojna životna iskustva. Porodični odnosi stvaraju psihološku sredinu koja je potrebna za procesiranje većine iskustava, što uključuje razumijevanje, pomoć, osjetljivost i odgovornost na potrebe djece. Stoga porodično okruženje predstavlja izvor socijalne podrške, kako za roditelje, tako i za djecu (Vasta, Haith & Miller, 1997). Sve navedeno djecu čini sigurnijom, a njima se time obezbjeđuje sigurno okruženje za razvoj. Relacije u porodici, koje prati suportivna komunikacija, značajne su za usvajanje i razvijanje vještina slušanja drugih, kao i za razvijanje empatije prema drugima, te za razvoj kooperativnih načina rješavanja problema (Zvizdić, 2015). Najveći broj ljudi prima emocionalnu podršku, toplinu, osjećaj pripadanja, materijalnu i instrumentalnu podršku u porodici. Porodica predstavlja jedan od glavnih trajnih i pristupačnih izvora socijalne podrške, kako odraslih, tako i djece, odnosno mladih. Za razliku od ostalih izvora socijalne podrške i pomoći, u porodici se najčešće prepoznaju problemi i pomoć se spontano pruža članu u krizi bez da to on posebno traži (Vrućinić, 2012).

U momentima kada u porodici postoje periodi neadekvatnog funkcionisanja, značajnu ulogu za pojedinca mogu imati vršnjaci. Podrška od strane vršnjaka ima posebnu važnost u periodu adolescencije, kada mladi sve više stižu nezavisnost od roditelja, umanjuju interakcije sa njima, a svoje socijalne kontakte proširuju izvan porodice. Ova podrška ne podrazumijeva samo podršku od strane prijatelja, već i od poznanika, drugova iz razreda, drugih vršnjaka iz nekih drugih grupa (Zvizdić, 2015). Odnosi sa vršnjacima-prijateljima doprinose razvoju mladih na taj način što omogućavaju prilike za učenje i razvijanje socijalnih vještina, obezbjeđuju zadovoljenje potrebe za intimnošću, daju priliku za zasnivanje drugarstva i prijateljstva, čime se redukuje socijalna izolacija (Cochran & Davila, 1992). Osim toga, ovi odnosi obezbjeđuju emocionalnu podršku i

sigurnost, posebno u stresnim periodima, kao i kod adaptacije djeteta na školsko okruženje, a potkrepljuju i školski uspjeh (Masten & Coatsworth, 1998). Podrška od strane vršnjaka doprinosi osjećaju sigurnosti time što se redukuju određeni problemi psihološke prirode. Mladi, kroz odnose sa vršnjacima, evaluiraju i shvataju brojne kritične aspekte vlastitih iskustava, te međusobno pružaju jedni drugima objašnjenja određenih socijalnih i fizičkih problema (Gordon & Wraith, 1993; Nelson & Aboud, 1985, prema Gottlieb, 1996).

Osim porodice i vršnjaka, škola predstavlja vrlo važan izvor socijalne podrške mladima koji može imati pozitivan uticaj na mlade, a posebno mjesto u školskom okruženju zauzimaju nastavnici. Upravo su oni agensi koji su izvor i moderatori brižnih i suportivnih odnosa, pozitivnih i visokih očekivanja, te prilika za doprinosom i participacijom, koji mogu predstavljati protektivne faktore. Svojim djelovanjem kroz proces odgoja i obrazovanja, nastavnici nastoje zadovoljiti osnovne potrebe mladih za sigurnošću, pripadnošću, ljubavlju, poštovanjem, učenjem, postignućem i efikasnošću. Nastavnici su edukatori – oni uče i razvijaju znanja, pružaju korisne informacije, ali i neophodnu instrumentalnu podršku, te podstiču sveukupni razvoj djeteta, vodeći brigu po njemu. Osim toga, nastavnik predstavlja pozitivan i povjerljiv model za ličnu identifikaciju, a uz to oni uče mlade da vjeruju u sebe, svoju budućnost, razvijajući tako autonomiju, samopoštovanje, samopouzdanje i optimizam, kao rezilijentne osobine (Zvizdić, 2015).

Značaj socijalne podrške

Socijalna podrška svojim neposrednim djelovanjem mijenja značenje životnog događaja i na taj način utiče na ishod krize, dok posrednim djelovanjem modifikuje reakcije na životni događaj i reakcije u krizi (Vrućinić, 2012). Istraživanja potvrđuju da socijalna podrška, osim što je veoma dobar prediktor dužeg života i boljeg zdravlja, ujedno utiče na dobrobit pojedinca koji prima socijalnu podršku, te pojedincu pomaže u što produktivnijem i efikasnijem suočavanju sa teško savladivim i stresnim situacijama (Hause i sar., 1988, prema Sarason i sar., 1990).

Percipirana socijalna podrška vodi napretku, oporavku i boljem suočavanju sa negativnim događajima u životu, jer dozvoljava osobi da razvija osjećaj vlastite vrijednosti, pozitivne samoevaluacije i jačanja svog socijalnog ja (Sarason i sar., 1986).

Kada se posmatra kao nezavisna varijabla, socijalna podrška je povezana sa zdravljem i općom dobrobiti, na direktan ili indirektan način. Socijalna podrška je u pozitivnom smislu povezana sa različitim aspektima dobrobiti pojedinca, a u negativnom smislu sa depresijom i psihološkom iscrpljenošću (Pugliesi, 1998).

1.5. Percipirana socijalna podrška u školskom kontekstu

Socijalna podrška od roditelja, nastavnika i vršnjaka ima značajan i višestruk uticaj na školski uspeh. Emocionalna, socijalna i akademska podrška čine osnovu za razvoj pozitivnih školski veza i motivacije kod učenika, čime se doprinosi njihovoj boljoj akademskoj izvedbi. Uloga socijalne podrške u školskom kontekstu ističe se kao ključni faktor koji može pomoći učenicima da ostvare svoj potencijal.

Roditeljska podrška je jedan od ključnih faktora koji utiče na akademski uspeh učenika. Istraživanja pokazuju da roditelji koji pružaju emocionalnu, socijalnu i praktičnu podršku svojim učenicima omogućavaju bolje akademske performanse. Roditeljski angažman, koji uključuje pozitivnu komunikaciju, pomaganje u učenju, kao i stvaranje stabilnog i podržavajućeg domaćinskog okruženja, značajno doprinosi većoj motivaciji i boljoj koncentraciji učenika (Masten et al., 2004)

Podrška koju učenici dobijaju od svojih nastavnika takođe ima značajan uticaj na njihov školski uspeh. Nastavnici koji se ponašaju kao mentori, pružajući emocionalnu podršku, smanjuju stres i povećavaju motivaciju učenika, što vodi ka boljim akademskim rezultatima. Pozitivni odnosi sa nastavnicima mogu poboljšati socijalnu i emocionalnu prilagodbu učenika, a to se u velikoj meri odražava na njihov akademski učinak (Cornelius-White, 2007).

U istraživanjima je pokazano da učenici koji percipiraju svoje nastavnike kao podržavajuće i zainteresovane za njihov napredak, bolje ostvaruju rezultate i bolje se snalaze u školskom okruženju (Pianta et al., 2002).

Podrška vršnjaka igra ključnu ulogu u razvoju socijalnih vještina i u povećanju motivacije za školu. Prijatelji i vršnjaci koji podržavaju učenike mogu povećati njihovu emocionalnu stabilnost i smanjiti osećaj stresa, što im omogućava da se bolje koncentrišu na školu. Vršnjački odnosi mogu pružiti emocionalnu podršku i smanjiti negativne efekte anksioznosti ili stresa u vezi sa školom. Studije su pokazale da postoji pozitivna korelacija između socijalne podrške vršnjaka i povećanja akademskih postignuća, jer učenici sa boljim socijalnim mrežama često lakše prevazilaze izazove školskog života (Wentzel, 1998).

Povezanost između socijalne podrške i školskog uspeha se manifestuje kroz različite mehanizme:

- Emocionalna podrška: Učenici koji dobijaju emocionalnu podršku od roditelja, nastavnika i vršnjaka imaju niži nivo stresa, što poboljšava njihovu sposobnost koncentracije i rešavanja problema, što direktno utiče na bolje akademske rezultate.
- Motivacija: Socijalna podrška povećava unutrašnju motivaciju učenika da postignu bolje akademske rezultate. Kada učenici osećaju da su podržani od strane drugih, lakše se angažuju u učenju i postizanju boljih rezultata (Gottfried, 1985).
- Samopouzdanje i socijalne veštine: Podrška od roditelja i vršnjaka pomaže učenicima da razviju samopouzdanje, koje je ključno za prevazilaženje izazova i postizanje školskih ciljeva. Takođe, socijalna integracija kroz vršnjačke odnose može doprineti povećanju angažovanosti i uspešnosti u školi (Harter, 1999).

METODOLOŠKI DIO RADA

Problem istraživanja

Savremeno obrazovanje postavlja sve veće zahtjeve pred učenike, očekujući od njih ne samo usvajanje akademskog znanja već i razvoj različitih socijalnih i emocionalnih kompetencija koje doprinose njihovom školskom uspjehu. Brojna istraživanja ukazuju da faktori poput motivacije, radnih navika i intelektualnih sposobnosti nisu jedini prediktori školskog postignuća, već da značajnu ulogu igra i socijalna podrška koju učenici percipiraju iz različitih izvora – roditelja, vršnjaka i nastavnika (npr. Wentzel, 1998, Malecki & Demaray, 2006, Rueger, Malecki & Demaray, 2010). Socijalna podrška može pružiti emocionalnu stabilnost, povećati osjećaj pripadnosti i samopouzdanja, te poslužiti kao zaštitni faktor u stresnim situacijama koje učenici doživljavaju u školskom okruženju (npr. Rosenfeld, Richman & Bowen, 2000, Wentzel, 2003, Stadler et al., 2010, Rueger, Malecki & Demaray, 2010,).

Pojedina istraživanja pokazuju da učenici koji dobijaju veću socijalnu podršku ostvaruju bolje rezultate u školi, imaju razvijenije strategije suočavanja sa akademskim izazovima i iskazuju veći nivo motivacije za učenje (npr. Tayfur & Sevim, 2016; Mackinnon, 2012; Jiahui, et al., 2023; Saeed et al., 2023; Ahmed et al., 2008). Međutim, iako postoji značajan broj studija koje istražuju ovu temu, konzistentnost rezultata varira, a malo je istraživanja koja se bave specifičnim kontekstom srednjoškola u Tuzlanskom kantonu. Stoga je neophodno dublje ispitati kako percipirana socijalna podrška doprinosi školskom postignuću učenika u ovom regionu.

Osnovni problem ovog istraživanja je ispitivanje relacije između percipirane socijalne podrške iz različitih izvora (roditelji, vršnjaci, nastavnici) i školskog postignuća učenika srednjih škola Tuzlanskog kantona.

Značaj istraživanja

Teorijski značaj rada očituje se u doprinosu ovog istraživanja teorijskom razumijevanju uloge socijalne podrške u školskom postignuću učenika srednjih škola. Iako postoje brojne studije koje se bave uticajem različitih faktora na školski uspjeh, specifična povezanost percipirane socijalne podrške i akademskih ishoda nije dovoljno istražena u kontekstu srednjoškolskog obrazovanja u Tuzlanskom kantonu. Analizom različitih izvora podrške (roditelji, vršnjaci, nastavnici) i njihovog uticaja na postignuće, ovo istraživanje može proširiti postojeće teorijske modele u oblasti psihologije obrazovanja i doprinijeti boljem razumijevanju socijalnih faktora koji utiču na uspjeh učenika.

Praktični značaj ovog rada se ogleda u tome što rezultati istraživanja mogu biti od koristi nastavnicima, školskim pedagogima, roditeljima i donosiocima obrazovnih politika, jer pružaju konkretne informacije o tome na koji način je socijalna podrška povezana sa školskim postignućem. Na osnovu dobijenih nalaza, moguće je kreirati strategije i programe usmjerene na jačanje socijalne podrške u školskom okruženju, poboljšanje komunikacije između učenika i nastavnika te podsticanje pozitivne vršnjačke interakcije. Takođe, rezultati mogu pomoći roditeljima da bolje razumiju važnost njihove podrške u obrazovnom procesu djece i prilagode svoje pristupe kako bi ih efikasnije motivisali i podržali u učenju.

U kontekstu društvenog značaja ovog rada, školsko postignuće učenika ima dugoročne posljedice ne samo za pojedinca već i za društvo u cjelini. Razumijevanje faktora koji doprinose akademskom uspjehu može pomoći u kreiranju obrazovnog sistema koji pruža bolje uslove za razvoj učenika, čime se smanjuje stopa školskog neuspjeha i osigurava kvalitetnija radna snaga u budućnosti. Jačanje socijalne podrške unutar školskog sistema može doprinijeti stvaranju pozitivne školske klime, većem zadovoljstvu učenika obrazovanjem i njihovoj boljoj pripremljenosti za dalji akademski i profesionalni razvoj, što dugoročno utiče na razvoj zajednice i društva.

Ciljevi istraživanja

Ciljevi ovog istraživanja su:

- Utvrditi u kojoj mjeri je percipirana socijalna podrška od strane roditelja povezana sa školskim postignućem učenika srednjih škola Tuzlanskog kantona.
- Utvrditi u kojoj mjeri je percipirana socijalna podrška od strane nastavnika povezana sa školskim postignućem učenika srednjih škola Tuzlanskog kantona.
- Utvrditi u kojoj mjeri je percipirana socijalna podrška od strane vršnjaka povezana sa školskim postignućem učenika srednjih škola na području Tuzlanskog kantona.
- Ispitati u kojoj mjeri je ukupna percipirana socijalna podrška povezana sa školskim postignućem učenika srednjih škola Tuzlanskog kantona.

Hipoteze istraživanja

U skladu sa ciljevima istraživanja, postavljene su slijedeće hipoteze:

H1 Percipirana socijalna podrška od strane roditelja značajno je povezana sa školskim postignućem učenika srednjih škola Tuzlanskog kantona.

H2 Postoji značajna povezanost pozitivnog smjera između percipirane socijalne podrške od strane nastavnika i školskog postignuća učenika srednjih škola Tuzlanskog kantona.

H3 Percipirana socijalna podrška od strane vršnjaka značajno je povezana sa školskim postignućem učenika srednjih škola na području Tuzlanskog kantona.

H4 Ukupna percipirana socijalna podrška je u značajnoj, pozitivnoj korelaciji sa školskim postignućem učenika srednjih škola Tuzlanskog kantona.

Metod istraživanja

Ovo istraživanje je sistematsko neeksperimentalno istraživanje, u kome se zaključci donose na osnovu dobijenih rezultata na ispitanom uzorku i u njemu će se koristiti:

Metoda teorijske analize - Kako metoda teorijske analize podrazumijeva analizu dostupne publikovane stručne i načune literature iz prethodnih istraživanja, ova metoda se na prvom mjestu koristila u stvaranju teorijske osnove istraživanja, sa ciljem da se teorijski rasvijetli problem ispitivanja i time omogući fokusiranje predmeta istraživanja, definisanje osnovnih pojmova, te da se utvrde ciljevi, zadaci i istraživačke hipoteze.

Survey istraživački metod - Ova metoda obuhvata sve operacije pomoću kojih se mogu izraditi sistematski podaci o stanovništvu ili uzorku stanovništva: intervjuom, razgovorom, telefonskim razgovorom, dopisom itd. Odgovara na pitanja kako se veliki broj ispitanika osjeća, ponaša i slično. Survey metod predstavlja empirijsko-neeksperimentalni pristup koji je korišten za ispitivanje mladih – učesnika istraživanja..

2.6. Uzorak ispitanika

Prelić, N. et al. (2025). Povezanost percipirane socijalne podrške sa školskim postignućem učenika srednjih škola. *STED Conference 14(2)*, 349-368.

Istraživanje je urađeno na prigodnom uzorku ispitanika. Uzorak je obuhvatio ukupno N=384 ispitanika i sam uzorak su činili učenici četiri srednje škole sa prostora Tuzlanskog kantona. Struktura uzorka je prikazana u Tabeli 1.

Tabela 1. Struktura uzorka prema socio-demografskim faktorima.

Table 1. Sample structure according to socio-demographic factors.

Varijabla	Socio-demografski faktori	Frekvencija	Procenat
Spol	Muški	189	49,2
	Ženski	195	50,8
Dob	15	58	15,1
	16	93	24,2
	17	109	28,4
	18	106	27,6
	19	18	4,7
Razred	I	96	25,0
	II	110	28,6
	III	90	23,4
	IV	88	22,9
Sredina življenja	Urbana	206	53,6
	Ruralna	178	46,4
Vrsta škole	Ekonomska škola	90	23,4
	Medicinska škola	101	26,3
	Elektrotehnička škola	97	25,5
	Gimnazija	96	25,0
Obrazovanje oca	Osnovna škola	18	4,7
	Srednja škola	247	64,3
	Viša ili visoka škola	119	31,0
Obrazovanje majke	Osnovna škola	108	28,1
	Srednja škola	215	56,0
	Viša ili visoka škola	61	15,9

Iz podataka, prikazanih u Tabeli 1 je vidljivo da je uzorak sačinjavalo nešto više ženskih ispitanika (195; 50,8%) u odnosu na muške muške (189; 49,2%), ali je spolna raspodjela gotovo izjednačena. Što se tiče dobi ispitanika, najviše ispitanika ima 17 godina (109; 28,4%), zatim slijede oni sa 18 godina (106; 27,6%). Nešto manje ih je u dobi od 16 godina (93; 24,2%), dok je najmanje onih koji imaju 15 godina (58; 15,1%) i 19 godina (18; 4,7%). Uzimajući u obzir razred koji učenici pohađaju, najviše ispitanika pohađa II razred (110; 28,6%), a odmah iza njega je I razred (96; 25,0%). Slijede učenici III razreda (90; 23,4%), dok je najmanje ispitanika iz IV razreda (88; 22,9%). Posmatrajući uzorak s obzirom na sredinu življenja, vidljivo je da nešto veći broj ispitanika dolazi iz urbanih sredina (206; 53,6%), dok ih je nešto manje iz ruralnih sredina (178; 46,4%). Učesnici istraživanja, kao učenici, pohađaju neku od četiri škole u kojima je istraživanje sprovedeno. Najviše ispitanika pohađa Medicinsku školu (101; 26,3%), a zatim slijede oni iz Elektrotehničke škole (97; 25,5%) i Gimnazije (96; 25,0%), dok je najmanje ispitanika Ekonomske škole (90; 23,4%).

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Posmatrajući uzorak s obzirom na obrazovanje roditelja, najveći broj ispitanika ima oca sa srednjom školom (247; 64,3%), zatim slijede oni čiji očevi imaju višu ili visoku školu (119; 31,0%), dok je najmanje ispitanika čiji su očevi završili samo osnovnu školu (18; 4,7%). Sa druge strane, najviše ispitanika ima majku sa srednjom školom (215; 56,0%); slijede oni ispitanici čije su majke završile osnovnu školu (108; 28,1%), dok najmanje ispitanika dolazi iz porodica gdje majka ima završenu višu ili visoku školu (61; 15,9%).

Varijable

Operacionalizacijom problema istraživanja, definisane su sljedeće nezavisne i zavisne varijable:

Zavisna varijabla

Školsko postignuće

Školsko postignuće se odnosi na nivo akademskog uspjeha učenika, koji se najčešće izražava preko ocjena, uspješno završenih zadataka i testova, kao i kroz angažman u nastavnim aktivnostima. Ova varijabla se kroz različita istraživanja odnosi na objektivne pokazatelje uspjeha (prosjeck ocjena, broj položenih ispita) i subjektivne aspekte, poput učenikovog zadovoljstva vlastitim postignućima, percepcije uspješnosti i motivacije za daljnje učenje. U ovom istraživanju, školsko postignuće je operacionalizovano preko informacije o općem uspjehu učeniku na kraju I polugodišta.

Nezavisne varijable

U istraživanje su uključene nezavisne varijable koje se odnose na percipiranu socijalnu podršku i to socijalnu podršku od strane roditelja, profesora, vršnjaka, kao i na ukupnu socijalnu podršku.

Percipirana socijalna podrška od strane roditelja

Percipirana socijalna podrška od strane roditelja odnosi se na učenikovo subjektivno viđenje podrške koju dobija od svojih roditelja. Ova podrška uključuje emocionalnu podršku (ohrabrivanje, razumijevanje i podsticanje), instrumentalnu podršku (pomoć u učenju, osiguravanje resursa za školovanje), kao i informativnu podršku (savjeti, vođenje kroz obrazovne i profesionalne odluke).

Percipirana socijalna podrška od strane nastavnika

Percipirana socijalna podrška od strane nastavnika odnosi se na učenikovu percepciju nastavničkog angažmana u vidu pružanja emocionalne, akademske i motivacione podrške. Ova varijabla uključuje nastavničku dostupnost za razgovor, pružanje konstruktivnih povratnih informacija, podsticanje učenika na akademski uspjeh, kao i stvaranje pozitivne i podržavajuće atmosfere u učionici.

Percipirana socijalna podrška od strane vršnjaka

Percipirana socijalna podrška od strane vršnjaka odnosi se na učenikovo viđenje pomoći, razumijevanja i podrške koju dobija od svojih vršnjaka. Ova podrška može biti emocionalna (prijateljstvo, osjećaj pripadnosti), instrumentalna (pomoć u učenju i rješavanju zadataka) i informativna (razmjena znanja i savjeta). Učenici s visokom percipiranom podrškom vršnjaka osjećaju se sigurnije, imaju veću motivaciju za školu i lakše se nose s akademskim izazovima.

Percipirana socijalna podrška (ukupna)

Percipirana socijalna podrška (ukupna) odnosi se na sveukupni nivo podrške koji učenik osjeća od strane roditelja, nastavnika i vršnjaka. Ova varijabla predstavlja zbir različitih izvora socijalne podrške i odražava koliko učenik doživljava svoje okruženje kao podsticajno i ohrabrujuće u akademskom i ličnom razvoju. Veća ukupna percipirana podrška povezana je sa višim nivoom psihološke dobrobiti učenika.

Mjerni instrumenti

U ovom istraživanju korišteni su sljedeći instrumenti ispitivanja:

- Upitnik o socio-demografskim podacima ispitanika i
 - Skala percipirane socijalne podrške
1. Upitnik o socio-demografskim podacima je konstruisan posebno za potrebe ovog istraživanja, kako bi se izvršio uvid u socio-demografske karakteristike ispitanika, a sadrži:
 - Pitanja o opštim biografskim podacima: pol, dob, sredina življena (urbana ili ruralna sredina), vrsta škole koju pohađa, razred, uspjeh u školi.
 - Pitanja o porodici: nivo obrazovanja oca, nivo obrazovanja majke.

2. Skala percipirane socijalne podrške služi za mjerenje percepcije pružene socijalne podrške. Percipirana socijalna podrška se odnosi na uvjerenje pojedinca da ga drugi vole, brinu za njega i žele mu pomoći, i ona je pozitivno i značajno povezana sa stvarnom ili dobijenom socijalnom podrškom. Za potrebe ovog istraživanja korištena je skala percipirane socijalne podrške koju su za djecu osnovnoškolske dobi konstruisali Dubow i Ullman (1989), a za naše govorno područje prevela i prilagodila S. Pupačić (1992). Skala sadrži tri subskale namjenjene mjerenju percipirane socijalne podrške od strane roditelja, nastavnika i vršnjaka. Sastoji se od 15 čestica., a za svaki od već spomenuta tri izvora podrške u upotrebi je bilo po pet čestica za koje su uzeti u obzir oni faktori koji ih najbolje predstavljaju. Procjenjivanje čestica vršeno je na skali od 1 (nikad) do 4 (uvijek), gdje je ukupni rezultat izražen kao suma procjena na svim česticama i subskalama. Viši rezultat predstavlja veću percipiranu socijalnu podršku. Pouzdanost pojedinih dimenzija ove skale na ispitanom uzorku, izraženu preko Cronbach-ovog Alfa koeficijenta interne pouzdanosti, iznosi: podrška od strane prijatelja – 0,714; pouzdanost od strane profesora – 0,753; pouzdanost od strane porodice – 0,822. Pouzdanost cijele skale iznosi 0,819. S obzirom na navedene vrijednosti, prihvatljiva je upotreba upitnika.

Procedura sprovođenja istraživanja i uzorak ispitanika

Opšti istraživački metod korišteno ovog istraživanja je neeksperimentalno, korelaciono istraživanje bez ponovljenih mjerenja. Za potrebe prikupljanja podataka primijenjeni su navedeni upitnici (Upitnik o socio-demografskim podacima i Skala percipirane socijalne podrške (Pupačić, 1992)).

Prikupljanje podataka od ispitanika je vršeno na prigodnom uzorku učenika u četiri tuzlanske srednje škole. Ova faza je realizirana u formi anketiranja. Budući da je sa svim srednjim školama uspostavljena izrazito dobra saradnja, dogovoreno je da se za potrebe ovog istraživanja odvoji vrijeme u okviru časa odjeljenske zajednice. Ispitivanje je provedeno metodom grupno vođenog rada, koje su koordinisali autori ovog rada. Od svih razrednika je zatraženo da prilikom dogovaranja termina za provođenje istraživanja učenicima naglasi da je učešće u ovoj studiji dobrovoljno, te da je u skladu sa tim potrebno prikupiti saglasnost učenika i njihovih roditelja/staratelja. Na početku ispitivanja, svim ispitanicima je u opštoj uputi obrazložena svrha istraživanja – naučni i aplikativni cilj projekta kao i način na koji će ono biti obavljeno. Još jednom je ukazano na dobrovoljnost učešća u istraživanju, te na izrazitu važnost iskrenosti – što tačnije davanje podataka. Kada je to bilo potrebno, ispitanicima su pružena i dodatna objašnjenja ili po njihovom zahtjevu i pomoć pri davanju odgovora na pitanja. Popunjavanje upitnika je trajalo do 20 minuta. Ispitivanje je sprovedeno tokom decembra 2024. i februara 2025.godine. Konačan uzorak obuhvatio je 384 ispitanika.

Statistička obrada podataka

Obrada prikupljenih podataka je izvršena pomoću statističkog programa SPSS for Windows 26.0. Rezultati su analizirani adekvatnim statističkim postupcima - kvantitativna obrada rezultata putem odgovarajućih statističkih deskriptora (mjera centralne tendencije, mjera varijabilnosti, kao i

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mjera asimetrije), Kolmogorov-Smirnov test za utvrđivanje normalnosti raspodjele podataka, mjera korelacije (Spearmanov koeficijent korelacije).

Za utvrđivanje povezanosti između zavisne sa nezavisnim varijablama, korišten je Spearmanov koeficijent korelacije, a kako bi se pratile razlike u nivou socijalne podrške vezano za svaku od kategorija vezanih za uspjeh, korišteni su odgovarajući deskriptivni statistički pokazatelji.

NALAZI ISTRAŽIVANJA

Deskriptivne statističke mjere

U nastavku su prikazani deskriptivni pokazatelji nezavisnih varijabli obuhvaćenih istraživanjem. Normalnost distribucije rezultata ispitanika ispitana je Kolmogorov-Smirnovim testom (Tabela 2).

Tabela 2. Deskriptivni pokazatelji nezavisnih varijabli u istraživanju i testiranje značajnosti odstupanja rezultata od normalne distribucije na uzorku N=384.

Table 2. Descriptive indicators of independent variables in the research and testing the significance of the deviation of the results from the normal distribution on the sample N=384.

Statistički parametar		A	B	C	D
Aritmetička sredina (M)		16,25	14,21	15,82	46,04
Standardna greška aritmetičke sredine		0,165	0,149	0,135	0,349
Interval pouzdanosti u kome se sa 95% sigurnosti nalazi aritmetička sredina	Donja granica	15,92	13,92	15,56	45,36
	Gornja granica	16,57	14,51	16,08	46,73
Trimovana aritmetička sredina (5%)		16,5	14,3	15,95	46,36
Medijana (Md)		17	14	16	47
Varijansa (V)		10,46	8,57	6,96	46,81
Standardna devijacija (SD)		3,24	2,93	2,64	6,84
Minimum		5	5	6	18
Maximum		20	20	20	59
Raspon		15	15	14	41
Interkvartilni raspon		5	4	4	9
Skjunis (mjera asimetrije distribucije)		-1,054	-0,413	-0,697	-0,731
Std.greška skjunisa		0,125	0,125	0,125	0,125
Kurtozis (mjera spljoštenosti distr.)		0,691	-0,091	0,111	0,976
Std.greška kurtozisa		0,248	0,248	0,248	0,248
Kolmogorov-Smirnov test	Statistik	0,154	0,099	0,136	0,069
	df	384	384	384	384
	sig.	<0,001	<0,001	<0,001	<0,001

Varijable: A – Percipirana socijalna podrška od strane roditelja, B – Percipirana socijalna podrška od strane nastavnika, C – Percipirana socijalna podrška od strane vršnjaka, D – Ukupna percipirana socijalna podrška

Na osnovu podataka prikazanih u Tabeli 2, koji se odnose na rezultate ispitanika na Skali percipirane socijalne podrške, vidljivo je da na Subskali percipirane socijalne podrške od strane roditelja ispitanici ostvaruju rezultate od 5 do 20, pa raspon iznosi 15. Prosječan rezultat na ovoj subskali iznosi $M=16,25$, dok medijana rezultata iznosi $Md=17$. Kada je u pitanju varijabilnost rezultata na Subskali percipirane socijalne podrške od strane roditelja, standardna devijacija iznosi $Sd = 3,24$, a koeficijent varijabilnosti je $V=19,94\%$. Vrijednost skjunisa je negativna ($Sk = -1,054$), a s obzirom na vrijednost standardne pogreške asimetrije (0,125), standardizovani skjunis iznosi 8,43, što govori da sa 99% sigurnosti distribucija podataka zbog asimetrije značajno odstupa

od normalne distribucije. Vrijednost kurtozisa je pozitivna ($Ku = 0,691$) i s obzirom na vrijednost standardne pogreške kurtozisa ($0,248$), standardni kurtozis ima vrijednost $2,786$, što ukazuje da distribucija podataka i po spljoštenosti odstupa od normalne. Ovaj podatak govori da je distribucija leptokurtična. Kolmogorov Smirnovljev test ukazuje da distribucija podataka na Subskali percipirane socijalne podrške od strane roditelja značajno odstupa od normalne distribucije sa $99,9\%$ sigurnosti ($p < 0,001$).

Podaci u Tabeli 2 dalje pokazuju da ispitanici na Subskali percipirane socijalne podrške od strane nastavnika ostvaruju rezultate također od 5 do 20, te raspon rezultata iznosi 15. Prosječan rezultat na ovoj subskali iznosi $M=14,21$, dok medijana rezultata iznosi $Md=14$. Što se tiče varijabilnosti rezultata na Subskali percipirane socijalne podrške od strane nastavnika, standardna devijacija iznosi $Sd=2,93$, pa je koeficijent varijabilnosti je $V=20,62\%$. Vrijednost skjunisa je negativna ($Sk = -0,413$), a s obzirom na vrijednost standardne pogreške asimetrije ($0,125$), standardizovani skjunis iznosi $3,30$, što govori da sa 99% sigurnosti distribucija podataka zbog asimetrije značajno odstupa od normalne distribucije. Vrijednost kurtozisa je također negativna ($Ku = -0,091$), dok je vrijednost standardne pogreške kurtozisa ($0,248$), pa standardni kurtozis iznosi $0,367$, što ukazuje da distribucija podataka po spljoštenosti ne odstupa značajno od normalne. Ovaj podatak govori da je distribucija mezokurtična. Kolmogorov Smirnovljev test ukazuje da distribucija podataka na Subskali percipirane socijalne podrške od strane nastavnika značajno odstupa od normalne distribucije sa $99,9\%$ sigurnosti ($p < 0,001$).

Podaci, koji se odnose na Subskalu percipirane socijalne podrške od strane vršnjaka ukazuju da ispitanici ostvaruju rezultate od 6 do 20, pa raspon rezultata iznosi 14. Prosječan rezultat na ovoj subskali je $M=15,82$, dok medijana rezultata iznosi $Md=16$. Kada se govori o varijabilnosti rezultata na ovoj subskali, standardna devijacija iznosi $Sd=2,64$, pa je koeficijent varijabilnosti je $V=16,69\%$. Vrijednost skjunisa je i na ovoj subskali negativna ($Sk=-0,697$), te s obzirom na vrijednost standardne pogreške asimetrije ($0,125$), standardizovani skjunis iznosi $-5,576$, što govori da sa 99% sigurnosti distribucija podataka po asimetriji značajno odstupa od normalne distribucije. Vrijednost kurtozisa iznosi $Ku=0,111$, a uzimajući u obzir vrijednost standardne pogreške kurtozisa ($0,248$), standardni kurtozis iznosi $0,448$, što kazuje da distribucija podataka po spljoštenosti ne odstupa značajno od normalne. Ovaj podatak govori da je distribucija mezokurtična. Kolmogorov Smirnovljev test ukazuje da distribucija podataka na Subskali percipirane socijalne podrške od strane nastavnika značajno odstupa od normalne distribucije sa $99,9\%$ sigurnosti ($p < 0,001$).

Tabela 2 prikazuje i podatke koji se tiču ukupne percipirane socijalne podrške. Na ovoj skali ispitanici ostvaruju rezultate od 18 do 59, pa raspon rezultata iznosi 41. Prosječan rezultat na ovoj subskali je $M=46,04$, dok medijana rezultata iznosi $Md=47$. Što se tiče varijabilnosti rezultata na ovoj skali, standardna devijacija iznosi $Sd=6,84$, pa je koeficijent varijabilnosti je $V=14,86\%$. Vrijednost skjunisa je negativna ($Sk=-0,731$), a s obzirom na vrijednost standardne pogreške asimetrije ($0,125$), standardizovani skjunis iznosi $5,848$, što kazuje da sa 99% sigurnosti distribucija podataka po asimetriji značajno odstupa od normalne distribucije. Vrijednost kurtozisa je $Ku=0,976$, pa uzimajući u obzir vrijednost standardne pogreške kurtozisa ($0,248$), standardni kurtozis iznosi $3,94$, što govori da distribucija podataka po spljoštenosti sa 99% sigurnosti odstupa značajno od normalne. Ovaj podatak ukazuje da je distribucija leptokurtična. Kolmogorov Smirnovljev test potvrđuje da distribucija podataka na Subskali percipirane socijalne podrške od strane nastavnika značajno odstupa od normalne distribucije sa $99,9\%$ sigurnosti ($p < 0,001$).

Uzimajući u obzir navedena odstupanja od normalne distribucije kod nezavisnih varijabli, kao i činjenicu da je zavisna varijabla na originalnom nivou mjerenja, pri obradi podataka su korišteni neparametrijski statistički postupci.

U Tabeli 3 su prikazani deskriptivni pokazatelji zavisne varijable. Iz prikazane tabele je vidljivo da je najveći dio učenika (120 ili $31,3\%$) u kategoriji vrlo dobrih, dok najmanje ima odličnih učenika ($n=62$ ili $16,1\%$). Nedovoljnih učenika u ispitanoj uzorku nije bilo, a broj dobrih i nedovoljnih učenika je približno jednak (dobrih: 100 ili $26,0\%$, nedovoljnih: 102 ili $26,6\%$). Prosječna ocjena na kraju I polugodišta na ispitanoj uzorku je bila $M=3,10$ ($SD=1,42$).

Prelić, N. et al. (2025). Povezanost percipirane socijalne podrške sa školskim postignućem učenika srednjih škola. *STED Conference 14(2)*, 349-368.

Tabela 3. Deskriptivni pokazatelji (frekvencije, kumulativne frekvencije, procenti i kumulativni procenti) zavisne varijable istraživanja (N=384).

Table 3. Descriptive indicators (frequencies, cumulative frequencies, percentages and cumulative percentages) of the dependent variables of the research (N=384).

	Frekvencija	Kumulativna frekvencija	Procenat	Kumulativni procenat
Odličan	62	62	16,1	16,1
Vrlo dobar	120	182	31,3	47,4
Dobar	100	282	26,0	73,4
Dovoljan	0	282	-	73,4
Nedovoljan	102	384	26,6	100,0
Ukupno	384		100,0	

Interkorelacija dimenzija percipirane socijalne podrške i školskog uspjeha učenika

U Tabeli 4 je predstavljena interkorelacija svih nezavisnih varijabli istraživanja (Percipirana socijalna podrška od strane roditelja (2), Percipirana socijalna podrška od strane nastavnika (3), Percipirana socijalna podrška od strane vršnjaka (4) i Ukupna socijalna podrška (5)) sa zavisnom varijablom (uspjeh učenika – školsko postignuće (1)). Povezanost svih varijabli međusobno prikazane su uz pomoć Spearmanovog koeficijenta korelacije.

Tabela 4. Matrica interkorelacija varijabli u istraživanju.

Table 4. Matrix of intercorrelations of variables in the research.

	1	2	3	4	5
1 Školski uspjeh	1,000				
2 Percipirana socijalna podrška od strane roditelja	-,057	1,000			
3 Percipirana socijalna podrška od strane nastavnika	,018	,360	1,000		
4 Percipirana socijalna podrška od strane vršnjaka	-,047	,350	,328	1,000	
5 Ukupna percipirana socijalna podrška	-,034	,733**	,690**	,673**	1,000

Povezanost percipirane socijalne podrške od strane roditelja sa školskim postignućem učenika srednjih škola Tuzlanskog kantona

Povezanost percipirane socijalne podrške od strane roditelja sa školskim uspjehom je prikazana u tabeli 3. Prikazani podatak kazuje da povezanost iznosi $r_c = -,057$ ($df=382$, $p>0,05$), što znači da povezanost između ove dvije varijable negativnog smjera, povezanost je zanemarivo mala, i ove dvije varijable na ispitanom uzorku dijele zanemarivo mali dio zajedničke varijanse. Figura 1 daje grafički prikaz povezanosti dvije navedene varijable.

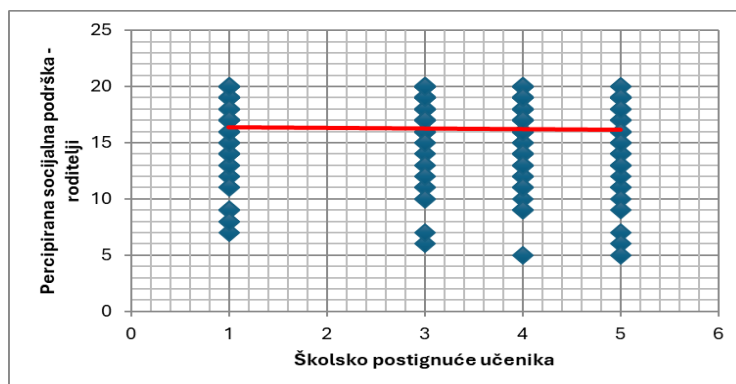


Figura 1. Grafički prikaz povezanosti Percipirane socijalne podrške od strane roditelja sa školskim uspjehom (Scatter dijagram).

Figure 1. Graphic representation of the relationship between Perceived social support by parents and school success (Scatter diagram).

Dobijeni podaci, koji opisuju povezanosti preko Spearmanovog koeficijenta korelacije i preko Scatter dijagrama, jasno ukazuju da se učenici, kojima je pružena veća socijalna podrška ne razlikuju po školskom postignuću značajno od učenika koji imaju manji nivo socijalne podrške, odnosno da školsko postignuće nije povezano sa percipiranom socijalnom podrškom od strane roditelja.

Na osnovu ovakvih podataka se hipoteza H1 odbacuje.

Povezanost percipirane socijalne podrške od strane nastavnika sa školskim postignućem učenika srednjih škola Tuzlanskog kantona

Povezanost percipirane socijalne podrške od strane nastavnika sa školskim uspjehom takođe je prikazana u tabeli 3. Prikazani podatak govori da je ova povezanost čak niža od prethodno navedene, te iznosi $r = ,018$ ($df=382$, $p>0,05$), odnosno da je povezanost između ove dvije varijable pozitivnog smjera, povezanost je zanemarivo mala, i ove dvije varijable na ispitanom uzorku dijele zanemarivo mali dio zajedničke varijanse. Figura 2 daje grafički prikaz povezanosti dvije navedene varijable.

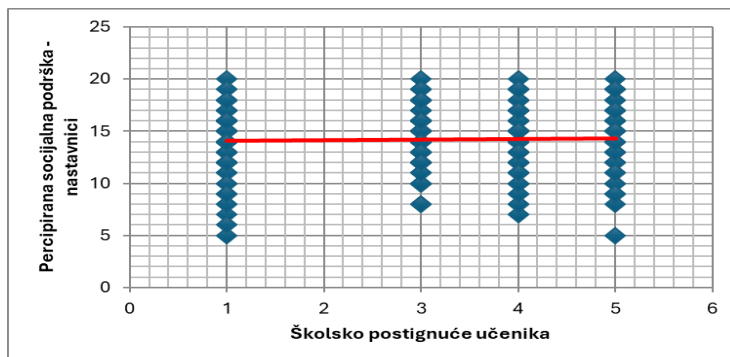


Figura 2. Grafički prikaz povezanosti Percipirane socijalne podrške od strane nastavnika sa školskim uspjehom (Scatter dijagram).

Figure 2. Graphic representation of the relationship between Perceived social support by teachers and school success (Scatter diagram).

Dobijeni podaci, koji opisuju povezanost preko Spearmanovog koeficijenta korelacije i preko Scatter dijagrama, jasno ukazuju da se učenici, kojima je pružena veća socijalna podrška (od strane nastavnika) ne razlikuju značajno od učenika koji imaju manji nivo ovog vida socijalne podrške, odnosno da školsko postignuće nije povezano sa percipiranom socijalnom podrškom od strane nastavnika.

Na osnovu ovakvih podataka se hipoteza H2 odbacuje.

Povezanost percipirane socijalne podrške od strane vršnjaka sa školskim postignućem učenika srednjih škola Tuzlanskog kantona

U Tabeli 3 je prikazan Spearmanov koeficijent korelacije između Percipirane socijalne podrške od strane vršnjaka i školskog uspjeha. Prikazani podatak govori da ova povezanost iznosi $r = -,047$ ($df=382$, $p>0,05$), odnosno, povezanost između ove dvije varijable je negativnog smjera, zanemarivo je mala, te zavisna i nezavisna varijabla na ispitanom uzorku dijele zanemarivo mali dio zajedničke varijanse. Figura 3 daje grafički prikaz povezanosti dvije navedene varijable.

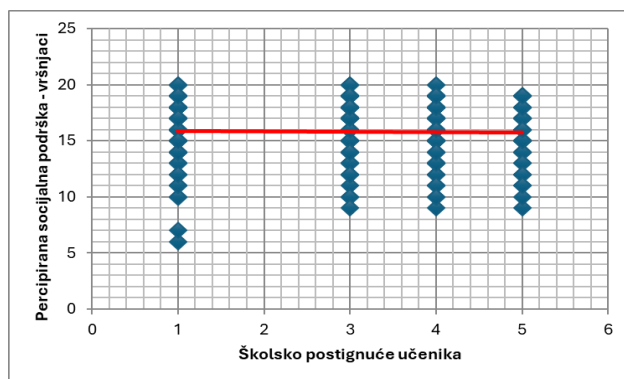


Figura 3. Grafički prikaz povezanosti Percipirane socijalne podrške od strane vršnjaka sa školskim uspjehom (Scatter dijagram).

Figure 3. Graphic representation of the association of Perceived social support from peers with school success (Scatter diagram).

Dobijeni podaci, koji opisuju povezanost preko Spearmanovog koeficijenta korelacije i preko Scatter dijagrama, jasno ukazuju da se učenici, kojima je pružena veća socijalna podrška (od strane vršnjaka) ne razlikuju po školskom postignuću značajno od učenika koji imaju manji nivo ovog vida socijalne podrške, odnosno da školsko postignuće nije povezano sa percipiranom socijalnom podrškom od strane vršnjaka.

Na osnovu ovakvih podataka se hipoteza H3 odbacuje.

Povezanost percipirane ukupne socijalne podrške sa školskim postignućem učenika srednjih škola Tuzlanskog kantona

S obzirom na već iznesene rezultate, koji se odnose na povezanost percipirane socijalne podrške od strane roditelja, nastavnika i vršnjaka sa školskim uspjehom, povezanost ukupne percipirane socijalne podrške sa zavisnom varijablom takođe je zanemarivo mala, statistički nije značajna i negativnog je smjera $r_s = -0,034$ ($df=382$, $p>0,05$). Figura 4 daje grafički prikaz povezanosti dvije navedene varijable.

Dobijeni podaci, koji opisuju povezanosti preko Spearmanovog koeficijenta korelacije i preko Scatter dijagrama, jasno ukazuju da učenici, kojima je pružena veća socijalna podrška (od strane roditelja, nastavnika i vršnjaka) se ne razlikuju po školskom postignuću značajno od učenika koji imaju manji nivo socijalne podrške, odnosno da školsko postignuće nije povezano sa percipiranom socijalnom podrškom.

Na osnovu ovakvih podataka se hipoteza H4 odbacuje.

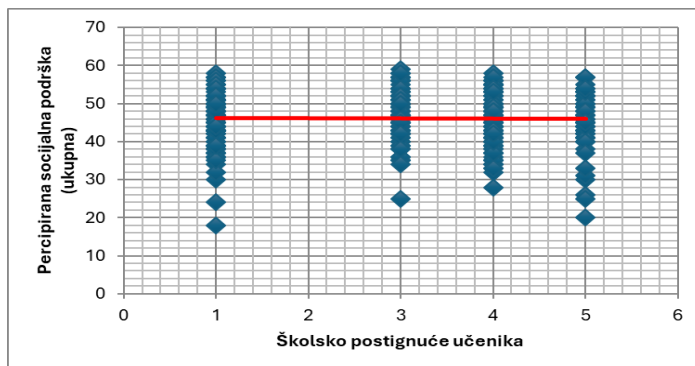


Figura 4. Grafički prikaz povezanosti Percipirane socijalne podrške (ukupno) sa školskim uspjehom (Scatter dijagram).

Figure 4. Graphic representation of the association of Perceived social support (total) with school success (Scatter diagram).

DISKUSIJA

Uprkos očekivanju da će percipirana socijalna podrška od strane roditelja, nastavnika i vršnjaka imati značajnu povezanost sa školskim postignućem učenika srednjih škola, rezultati istraživanja nisu potvrdili postavljene hipoteze. Dobijene korelacije su niske i nisu ukazale na značajnu povezanost ovih nezavisnih varijabli sa zavisnom varijablom. Mogući razlozi za ovakve nalaze se mogu razmotriti kroz nekoliko aspekata.

Roditeljska podrška tradicionalno se smatra vrlo važnim faktorom u obrazovnom uspjehu učenika. Međutim, nekoliko faktora može objasniti zašto u ovom istraživanju nije pronađena značajna povezanost:

Autonomija učenika – U srednjoškolskom uzrastu učenici često postaju nezavisniji i manje zavisni od roditeljske pomoći u učenju. Kako prelaze u više razrede, postaju odgovorniji za sopstvene akademske uspjehe, razvijaju strategije učenja i prilagođavaju se školskim zahtevima bez stalne roditeljske intervencije. Stoga, podrška roditelja može imati manji direktni uticaj na školski uspjeh nego u ranijim obrazovnim fazama, dok podrška roditelja sada može uticati na emocionalnu stabilnost učenika više nego na njihovo direktno školsko postignuće (Steinberg & Silverberg, 1986)

Individualna percepcija podrške – Nije nužno da objektivna roditeljska podrška odgovara subjektivnoj percepciji učenika. Na primjer, neki učenici mogu dobijati značajnu podršku, ali je ne percipiraju kao korisnu ili relevantnu za njihovo obrazovanje. Takođe, učenici sa slabijim akademskim postignućem mogu podršku roditelja tumačiti kao pritisak, dok oni sa boljim uspjehom mogu doživjeti istu podršku kao podsticajnu (Beecher & Loescher, 1994).

Roditeljska podrška u drugim aspektima – Podrška roditelja može biti usmjerena na emocionalno blagostanje, motivaciju i opšte odgojne vrijednosti, a ne nužno na akademska postignuća. Roditelji mogu više uticati na dugoročne obrazovne ciljeve, ali ne i na trenutne ocjene učenika (Pinquart & Silbereisen, 2004).

Na osnovu iznesenog se može zaključiti da dok roditeljska podrška ima značajan uticaj na emocionalnu stabilnost učenika, njen direktni uticaj na školski uspjeh opada kako učenici postaju stariji i razvijaju veću autonomiju. U srednjoškolskom uzrastu učenici postaju sve samostalniji u procesu učenja i razvijaju svoje strategije, dok roditeljima postaje teže da direktno utiču na njihov akademski uspjeh. Ipak, podrška roditelja u ovom uzrastu i dalje igra ključnu ulogu u očuvanju emocionalne stabilnosti učenika, što indirektno može pozitivno uticati na njihov školski uspjeh, kroz smanjenje stresa i povećanje motivacije.

Iako su nastavnici ključni akteri u obrazovnom sistemu, nekoliko razloga može objasniti nisku povezanost, odnosno izostanak povezanosti podrške nastavnika sa školskim postignućem:

Različiti stilovi učenja – Neki učenici više vrednuju individualni rad i manje zavise od podrške nastavnika, dok drugima podrška nastavnika može biti ključna. Ako učenik nije navikao da traži pomoć, možda neće ni percipirati dostupnu podršku nastavnika, što može rezultirati niskom korelacijom između ove varijable i školskog uspjeha (Zimmerman & Schunk, 2001). Osim toga, učenici koji smatraju da nisu u mogućnosti da odgovore na učiteljeve zahteve ili se osećaju nesigurno u akademskom okruženju mogu biti manje motivisani da traže pomoć, što može negativno uticati na njihov uspjeh, čak iako postoji objektivna podrška. U ovom kontekstu, motivacija učenika igra ključnu ulogu u tome da li će percipirati nastavničku podršku kao korisnu (Deci et al., 1991).

Akadska podrška vs. emocionalna podrška – Nastavnici mogu pružati emocionalnu podršku, ali to ne znači nužno da učenici zbog toga ostvaruju bolji akademski uspjeh. Ponekad se podrška ogleda u podsticanju samopouzdanja, što može imati dugoročnije efekte, ali ne mora odmah uticati na ocjene. Takođe, učenici koji su akademski uspješni mogu u manjoj mjeri tražiti podršku nastavnika, dok učenici sa slabijim uspjehom mogu osjećati da nisu dovoljno podržani, što može uticati na njihovu percepciju nastavničke pomoći (Wentzel, 1998)

Kontekst školskog sistema – U srednjim školama nastavnici često imaju veći broj učenika i ograničeno vrijeme za individualni rad, što može umanjiti percepciju dostupnosti njihove podrške. Pored toga, školski sistem često vrednuje samostalnost učenika, pa podrška nastavnika može biti

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više usmjerena na vođenje nego na direktnu pomoć u učenju (Leithwood & Jantzi, 2006, Guskey, 2002, Hattie, 2009)

Podrška vršnjaka igra značajnu ulogu u emocionalnom i socijalnom životu učenika, ali njena povezanost sa školskim postignućem može biti ograničena zbog nekoliko faktora:

Vrsta podrške – Vršnjaci najčešće pružaju emocionalnu i socijalnu podršku, ali ne nužno i akademsku podršku. U nekim slučajevima, grupni pritisak ili socijalizacija mogu čak negativno uticati na školski uspjeh. Na primjer, učenici koji provode više vremena u društvenim aktivnostima sa vršnjacima mogu imati manje vremena za učenje, što može uticati na njihove akademske rezultate (Wentzel, 1998, Brown & Larson, 2002)

Akadska kompetitivnost – Učenici mogu imati podršku vršnjaka, ali u kompetitivnom školskom okruženju ta podrška može biti manje usmjerena na akademske ciljeve i više na socijalne aspekte života. Takođe, učenici mogu oklijevati da traže akademsku pomoć od vršnjaka zbog straha od negativne procjene ili osjećaja rivalstva (Brown & Larson, 2002, Fletcher et al., 2003, Ryan & Patrick, 2001).

Divergentne akademske aspiracije – Ako učenici imaju prijatelje sa različitim akademskim ambicijama, percipirana podrška vršnjaka možda neće igrati značajnu ulogu u oblikovanju njihovog školskog postignuća. Učenici iz različitih obrazovnih sredina mogu imati drugačija očekivanja i vrijednosti kada je riječ o akademskom uspjehu (Juvonen & Murdock, 1997).

Ukupna socijalna podrška, koja uključuje podršku roditelja, nastavnika i vršnjaka, može imati sinergijski efekat, ali nekoliko razloga može objasniti zašto ona nije značajno povezana sa školskim postignućem:

Individualne razlike u učenju – Svaki učenik drugačije reaguje na socijalnu podršku. Dok nekima podrška roditelja, nastavnika i vršnjaka pruža osjećaj sigurnosti i motivacije, drugima može biti irelevantna u kontekstu akademskih postignuća. Neki učenici razvijaju sopstvene strategije učenja i ne oslanjaju se na podršku, dok drugi više zavise od spoljašnjih faktora. Takođe, emocionalno stabilni učenici mogu imati visok uspjeh bez obzira na percepciju socijalne podrške, dok oni koji se suočavaju sa većim emocionalnim izazovima mogu biti više pogođeni njenim nedostatkom (Zimmerman, 2000, Furman, 1985).

Školski uspjeh kao multifaktorska pojava – Pored socijalne podrške, školski uspjeh zavisi od kognitivnih sposobnosti, motivacije, radnih navika, organizacije vremena i socioekonomskog statusa porodice. Socijalna podrška može doprinijeti akademskom postignuću, ali nije jedini niti dominantni faktor. Učenici sa visokim samopouzdanjem i radnim navikama mogu postići dobre rezultate bez obzira na podršku, dok učenici sa slabijim strategijama učenja mogu imati teškoće čak i uz visoku percipiranu socijalnu podršku (Carroll, 1993, Bandura, 1997, Wentzel, 1998).

ZAKLJUČCI

Osnovni problem, kojim se ovo istraživanje bavilo jeste ispitivanje povezanosti socijalne podrške od strane roditelja, nastavnika i vršnjaka sa školskim postignućem učenika srednjih škola Tuzlanskog kantona. U vezi sa tim, definisani su ciljevi i postavljene odgovarajuće hipoteze. Kako bi se odgovorilo na postavljene hipoteze, ispitivanje je sprovedeno sa N=384 ispitanika, učenika ekonomske, elektrotehničke, medicinske škole i gimnazije sa područja Tuzlanskog kantona. Analizirajući dobijene rezultate, došlo se do sljedećih zaključaka:

Percipirana socijalna podrška od strane roditelja nije u značajnoj povezanosti sa školskim postignućem učenika srednjih škola Tuzlanskog kantona, što znači da razlike u uspjehu učenika ne postoje bez obzira na količinu pružene socijalne podrške od strane roditelja. Na osnovu ovakvog nalaza se odbacuje hipoteza H1.

Percipirana socijalna podrška od strane nastavnika takođe nije u značajnoj povezanosti sa školskim postignućem učenika srednjih škola Tuzlanskog kantona. Ovo ukazuje da razlike u uspjehu učenika ne postoje bez obzira na količinu pružene socijalne podrške od strane nastavnika. Na osnovu ovakvog nalaza se odbacuje hipoteza H2.

Percipirana socijalna podrška od strane vršnjaka nije u značajnoj povezanosti sa školskim postignućem učenika srednjih škola Tuzlanskog kantona, što govori da razlike u uspjehu učenika

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ne postoje bez obzira na nivo pružene socijalne podrške od strane vršnjaka. Na osnovu ovakvog nalaza se odbacuje hipoteza H3.

Ukupna percipirana socijalna podrška nije u značajnoj povezanosti sa školskim postignućem učenika srednjih škola Tuzlanskog kantona, što govori da razlike u uspjehu učenika ne postoje bez obzira na količinu pružene socijalne podrške od strane roditelja, nastavnika i vršnjaka. Na osnovu ovakvog nalaza se odbacuje hipoteza H4.

Sveukupno posmatrajući, ovakvi nalazi istraživanja ukazuju na to da percipirana socijalna podrška nije značajno povezana sa školskim postignućem učenika srednjih škola. Ovi nalazi sugerišu da buduća istraživanja treba da razmatraju dodatne varijable koje mogu medijatorski ili moderatorski uticati na odnos između socijalne podrške i školskog postignuća, uključujući individualne razlike u učenju, motivaciju i karakteristike školskog sistema.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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CONNECTION OF PERCEIVED SOCIAL SUPPORT WITH THE SCHOOL ACHIEVEMENT OF HIGH SCHOOL STUDENTS

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ABSTRACT

Great demands have been constantly made before students by contemporary education, expecting them not only to acquire academic knowledge, but also the development of various social and emotional competencies that contribute to their school success. Numerous studies indicate that factors such as motivation, work habits and intellectual abilities are not the only predictors of school achievement, but that the social support that students perceive from various sources – parents, peers and teachers – also plays a significant role. Some researches show that students who receive greater social support perform better in school, have more developed strategies for coping with academic challenges, and express a higher level of motivation for learning (e.g. Tayfur & Sevim, 2016; Mackinnon, 2012; Jiahui, et al., 2023; Saeed et al., 2023; Ahmed et al., 2008). Although there is a significant number of studies researching this topic, the consistency of the results varies. The goal of this paper was to determine whether there is a connection between the perceived social support by parents, teachers and peers, as well as the overall perceived social support and school achievement of high school students of Tuzla Canton. 384 respondents (50,8% female and 49,2% male respondents), students of four high schools from Tuzla Canton area, participated in the research. Data on the variables of the survey were collected through a questionnaire of sociodemographic data, designed specifically for the purposes of this research and the Perceived Social Support Scale (Dubow, Ullman, 1989), which is used to assess the support of parents, teachers and peers. Despite expectations that the perceived social support by parents, teachers and peers will have a significant connection with the school achievement of high school students, the hypotheses were not confirmed by the results of the research. The obtained correlations were low and did not indicate a significant connection of the independent variables with the dependent variable. When it comes to high school age, these findings suggest that future researches should consider additional variables that may affect the relationship between the social support and the school achievement in a mediator or moderator way, including individual differences in learning, motivation and school system characteristics.

Keywords: perceived social support, school achievement.

VAŽNOST VEZE IZMEĐU PORODICE I ŠKOLE (PEDAGOGA/PSIHOLOGA)

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SAŽETAK

Odnos porodice i škole je uvijek aktuelna tema. Saradnja porodice i škole implicira po sebi tradicionalni duh. Saradnja u odgojno-obrazovnom procesu se ranije odnosila prije svega na najosnovnije relacije među roditeljima i školom. Sa druge strane partnerstvo škole (odgajatelja, pedagoga/psihologa) i roditelja (porodice) je posebno značajno i ono je na tragu usklađivanja odgojnih utjecaja koji su proizvod neposredne komunikacije između škole (odgajatelja, pedagoga/psihologa) i roditelja (porodice) tokom raznovrsnih neposrednih kontakata dvije odgojne sredine. Obje odgojne sredine nose obaveze i odgovornosti. Iz školske klime u partnerstvo se uključuju (osim odgajatelja i pedagoga/psihologa) i školski menadžment, te ostali članovi saradničkog tima (ukoliko ih ima): socijalni radnici i bibliotekari. Osnovni cilj ovog istraživanja je da se provjeri postoji li statistički značajna razlika u percepciji roditelja učenika osnovnih škola na području Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja roditelja i mjesto stanovanja. U istraživanju je učestvovalo ukupno 700 ispitanika sa područja Srednjobosanskog kantona.

Ključne riječi: porodica, škola, saradnja, partnerstvo.

UVOD

Mak Ajvera, porodicu definiše kao „grupu koja određuje toliko precizna i trajna polna veza, da je time osigurano rađanje i odgoj djece“. Isti autor ističe da porodica određuje slijedećih pet ključnih karakteristika: Odnos muškarca i žene, Bračna forma na osnovu koje nastaje i odražava se odnos muškarca i žene, Sistem koji utvrđuje način određivanja potomaka, Ekonomska djelatnost koja se specijalno odnosi na potrebe u vezi sa rađanjem i odgojem djece i Zajednički stan, dom ili domaćinstvo. Odgojno-obrazovnu instituciju čine svi zaposleni u toj instituciji, svi procesi (od njenih ulaza do izlaza iz odgojno-obrazovne institucije, zatim ishoda i efekata) i odnosi unutar te institucije. Odgojno-obrazovna institucija nastoji ostvariti neposredne rezultate obrazovnog procesa (obrazovne ishode) i obrazovnu produkciju (izlaze), odnosno odgojno-obrazovne ciljeve uz što nižu cijenu, odnosno što efektivnije i efikasnije. Sigurnost djeteta gradi se na slijedećim pretpostavkama ili uslovima: Zaštita od vanjskih utjecaja (koliko porodica štiti dijete i kako); Zadovoljavanje osnovnih potreba (Maslow, Erikson, Zazo i dr.); Koherentnost i stabilnost miljea u kome živi i u kome se razvija dijete. Osjećaj prihvaćenosti u vlastitom okruženju i to: kao član porodice - biti voljen i pružiti ljubav, biti izvor radosti i zadovoljstva za druge, biti vođen i usmjeravan (Vigotski); kao individue (persone) - prihvatanje individualnih osobina, mogućnost za aktivno učešće i sticanje iskustva određeni stepen slobode. Pozitivna obilježja pedagoške klime susreću se u slijedećim situacijama: ako su roditelji iskreni, pažljivi, razumiju dječije probleme, dijele ih sa njima, kada se raduju i vesele s djecom, a u slučaju opasnosti po razvoj djeteta postaju strogi i ozbiljni, ukoliko su emotivno zreli i njihovi se odnosi zasnivaju na međusobnoj ljubavi i ljubavi prema djetetu, ukoliko su brižni, a ne pretjerano, nastoje zadovoljiti dječije potrebe, ne gušeći njihovu slobodu, fleksibilni, dopuštaju da dijete iskaže svoje kompetencije, potiču dječiju samostalnost. Iz pedagoške literature vidljivo je da ne postoji univerzalna definicija odgovornog roditeljstva, ali osnovne odrednice ovog pojma odnose se na odgovornost bračnih drugova, planiranje porodice, odnos prema djeci, te uopšteno gledano svijest o postojanju roditeljskih

odabira koji dugoročno pozitivno utječu na rast i razvoj djeteta. Teško je dotaknuti se ove teme, a ne spomenuti roditeljske odgojne stilove. Jedan od odgojnih stilova su autoritativni/demokratski roditelji koji karakteriše topao i brižan odnos uz prisustvo kontrole i zahtjeva. Permisivni/Laissez-fair roditelji imaju topao i brižan odnos uz odsustvo kontrole i zahtjeva dok autoritarni/autokratski roditelji imaju hladan i nebrižan odnos uz prisustvo kontrole i zahtjeva; Još jedna vrsta su indiferentni/nezainteresovani roditelji - hladan i nebrižan odnos uz odsustvo kontrole i zahtjeva. Nakon lutanja kroz desetljeća u traganju za rješenjima koja će unaprijediti dosta loša iskustva u (ne)saradnji porodice i škole, stvari se temeljno mijenjaju i sve se snage usmjeravaju na približavanje i izjednačavanje odgojno-obrazovnih ciljeva sa istim interesima ove dvije odgojne sredine kako bi razvoj učenika, odnosno formiranje dječije ličnosti bilo u skladu sa opće društvenim kriterijima, a na zadovoljstvo sve tri zainteresovane strane: porodice (roditelja), škole (učitelja, nastavnika, pedagoga) i lokalne zajednice (društva). Partnerski odnosi porodice (roditelja) i škole (učitelj, nastavnik, pedagog) su za dječiji razvoj posebno važni. Brojni autori, poput Dunsta i Trivettea (2010) smatraju da je partnerstvo u neposrednoj vezi sa postignućima djece (ishodima). Na istom tragu su i Tolan i Woo (2010), te Dewore i Bowers (2006) i Keen (2007) koji te dječije ishode prepoznaju kroz redovan dolazak u školu, izvršavanje svojih obaveza tokom dana, poštujući pravila i dr. Mnogo je razloga koji u prvi plan stavljaju saradnju porodice (roditelja) i škole u procesu odgoja djece: brojni zadaci odgoja mladih mogu se realizovati samo uz zajedničko angažovanje porodice i škole što nameće potrebu njihove tijesne saradnje u procesu odgoja. U odgojnom radu jako je bitna koordinacija svih odgojnih faktora što ukazuje na neophodnost koordiniranja njihovih aktivnosti radi što veće efikasnosti i racionalizacije odgojnog procesa. Sve češća pojava različitih vidova poremećaja u ponašanju zahtijeva koordiniranu akciju porodice i škole na njihovom eliminisanju i otklanjanju. Pojam saradnja je uži pojam od pojma partnerstvo na što nas upućuje i bosanskohercegovačka profesorica sa Filozofskog fakulteta u Sarajevu Adila Pašalić Kreso (2004), koja potvrđuje i kandidira terminološke razlike između ova dva pojma pa konstatuje: "saradnja razvija i njeguje uglavnom površne i formalne odnose koji ma koliko da su učestali ne mogu donijeti kvalitativne promjene" misleći na konačan ishod u kome će se desiti promjene prema djetetu, odnosno, drugačije percipiranje njegove uloge. Partnerstvo porodice (roditelja) i škole (učitelj, nastavnik, pedagog/psiholog) u odgoju i razvoju djece školskog uzrasta veoma je važna i novija tema zbog sve veće uloge koju ovo partnerstvo ima u odgojno-obrazovnom radu.

METOD

Predmet i cilj istraživanja

Predmet istraživanja ovog rada pod nazivom „Važnost veze između porodice i škole (pedagoga/psihologa)“ kao jedan od najvažnijih dijelova idejnog projekta, je školski pedagog/psiholog, i njegova uloga u uspostavljanju partnerskih odnosa između škole i roditelja. Dakle, predmet istraživanja su stavovi roditelja o saradnji roditelja (obitelji) i škole (učitelja, nastavnika, pedagoga).

Posebni cilj istraživanja ovog rada je utvrđivanje roditeljskih stavova o važnosti saradnje između škole i roditelja u osnovnim školama na području Srednjobosanskog kantona.

Hipoteza

Ne postoji statistički značajna razlika u stavovima roditelja učenika osnovnih škola na području Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja i mjesto stanovanja roditelja.

Uzorak

Uzorkom je obuhvaćen 701 roditelj od čega je bilo 251 muških ili 35.90 % i 449 ženskih ispitanika ili 64.10 %. Prema starosnoj dobi u istraživanju je učestvovalo 38 ispitanika sa manje od 30 godina ili 5.40%, od 30 - 35 godina starosti učestvovalo je 155 roditelja ili 22.10 %, od 36-45 je bilo 343 ili 49.00 % roditelja, od 46-55 je bilo 135 roditelja ili 19.30% dok u starosnoj grupi iznad 55 godina nije bio ni jedan roditelj. Prema stepenu obrazovanja 125 roditelja ili 17.90 % je sa

završenom osnovnom školom, 378 ili 54.00 % roditelja je sa srednjom stručnom spremom, više stručnu spremu ima 62 roditelja ili 8.90 %, visoku stručnu spremu ima 114 roditelja ili 16.30 % dok je 21 ili 3.00 % roditelja sa masterom ili doktoratom.

Uzorak kao podskup temeljnoga skupa, se uzima u svrhu ispitivanja svojstava toga skupa i on treba biti reprezentativan, odnosno treba da zadovolji svojom brojnošću, spolnom, uzrasnom i obrazovnom raznovrstošću. Ovim istraživanjem je obuhvaćena populacija roditelja učenika u osnovnim školama na području Srednjobosanskog kantona i to u općinama: Bugojno, Busovača, Donji Vakuf, Fočnica, Gornji Vakuf-Uskoplje, Jajce, Kiseljak, Kreševo, Novi Travnik, Travnik i Vitez.

Instrumenti

Instrumenti istraživanja su alati koji se koriste u procesu prikupljanja podataka o nekom problemu, koji želimo istražiti i doći do željenih pokazatelja. U ovom istraživanju je korišten anketni upitnik i skala procjene (Likertov tip) za nastavnike. Pored općih podataka koji se odnose na spol, dob, školsku spremu i mjesto stanovanja upitnik sadrži pitanja gdje se vodilo računa o logičkoj strategiji grupisanja pitanja koja sačinjavaju hipotezu.

Na pitanja (varijable) se odgovara petostepenom Likertovom skalom od čega su dva stepena skale vezana za slaganja, jedan neutralan i dva neslaganja. Ispitanici (roditelji) su svoja mišljenja i stavove o ponuđenim tvrdnjama (slaganja, neutralnost i neslaganja) izražavali putem skale: *1 = uopće se ne slažem, 2 = ne slažem se, 3 = nemam mišljenja / neutralan sam, 4 = slažem se, 5 = potpuno se slažem*. Pitanja se, dakle, odnose na bitne faktore saradnje školskog pedagoga/psihologa i roditelja.

Uvažavajući specifičnost i složenost teme, kao i samog problema i predmeta istraživanja, pristup izradi instrumenta istraživanja je također bio zahtjevan, složen i kompleksan, da bi zadovoljili cilj. Od instrumenata istraživanja je korišten anketni upitnik – skala procjene (Likertov tip) za roditelje, koji se sastoji od 32 pitanja (varijabli) svrstanih u 8 grupa, a mi za potrebe ovog rada izdvajamo 4 varijable koje se odnose na bitne faktore saradnje školskog pedagoga/psihologa i roditelja.

Metode obrade podataka

Analizu i obradu prikupljenih podataka korištenjem softverskog paketa SPSS.

REZULTATI

Statistički značajna razlika u percepciji roditelja učenika osnovnih škola na području Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja roditelja i mjesto stanovanja, ne postoji.

Provjera pouzdanosti mjerne skale, po procjeni roditelja, od 4 indikatora saradnje školskog pedagoga/psihologa i roditelja, Kronbahovim koeficijentom ALFA = 0,742, ukazuje na dobru pouzdanost i unutrašnju saglasnost skale za ovaj uzorak ispitanika, bez obzira na mjernu skalu manju od 10 stavki. Srednja vrijednost korelacije između parova vrijednosti na skali iznosi 0,42 (optimalna između 0,20 i 0,40).

Izračunata aritmetička sredina (M) svih indikatora od 4,18 pokazuje da su faktori saradnje školskog pedagoga/psihologa i roditelja, po procjeni roditelja, veoma važni. Vrijednost standardne devijacije (SD) od 0,77 ukazuje da je rasipanje oko aritmetičke sredine veoma malo, što potvrđuje i koeficijent varijabilnosti (CV) od 18,42%, a time i veoma dobru homogenost dobivenih rezultata za ovaj uzorak ispitanika (Tabela 1).

Ispitanici u većini se slažu i potpuno slažu da su stvaranje radnog ambijenta, zdravo i sigurno okruženje, sredina u kojoj dijete raste i sredina u kojoj se nalazi škola bitni faktori saradnje školskog pedagoga/psihologa i roditelja.

Tabela 1. Mjere centralne tendencije, varijabilnosti i distribucije frekvencije obilježja Saradnja školskog pedagoga/psihologa i roditelja.

Table 1. Measures of central tendency, variability and frequency distribution of the characteristic Collaboration between school pedagogue/psychologist and parents.

Indikator	N	M	SD	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
SŠPR9	700	4,02	,79	0,30	2,40	22,00	45,90	29,40
SŠPR10	700	4,37	,71	0,10	1,00	9,70	40,30	48,90
SŠPR11	700	4,26	,75	0,70	1,10	10,90	45,60	41,70
SŠPR12	700	4,07	,89	1,40	3,00	19,00	39,90	36,70

Agenda: SŠPR - saradnja školskog pedagoga/psihologa i roditelja 9 - 12; N -ukupan broj ispitanika; M - aritmetička sredina; SD - standardna devijacija.

Tabela 2. Saradnja školskog pedagoga/psihologa i roditelja – upoređivanje po spolu (t-test).

Table 2. Cooperation between school pedagogue/psychologist and parents - comparison by gender (t-test).

Parametri	spol	N	M	SD	Razl. M	F	Znač.	t-vrijed.	Znač.
SŠPRZ	M	251	4,20	,58	,03	,302	,583	,548	,584
	Ž	449	4,17	,60					

Agenda: SŠPRZ-saradnja školskog pedagoga/psihologa i roditelja (zbirno); N-ukupan broj ispitanika; M- aritmetička sredina; SD-standardna devijacija; Razl. M-razlika aritmetičkih sredina; F i Znač.- Levenov test jednakosti varijansi; t-vrijed. i Znač.- vrijednost t-testa i njegova značajnost.

Vrijednost $t = ,548$ i njegova značajnost $Sig. = ,584$ nam ukazuju da ne postoji statistički značajna razlika u stavovima između roditelja s obzirom na njihov spol u percepciji saradnje sa školskim pedagogom/psihologom (Tabela 1). Na osnovu aritmetičke sredine (M) uočavamo da ispitanici muškog spola imaju pozitivnije stavove u odnosu na ispitanike ženskog spola te da je odstupanje od aritmetičke sredine (SD) veće kod ispitanika ženskog spola. Na osnovu dobivenih rezultata zaključujemo da je potvrđen prvi dio naše hipoteze da *statistički značajna razlika u percepciji roditelja učenika osnovnih škola na području Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja roditelja i mjesto stanovanja, ne postoji.*

Vrijednost F-testa i njegova značajnost (Sig.) pokazuju da postoji statistički značajna razlika između roditelja s obzirom na dob o saradnji školskog pedagoga/psihologa i roditelja (Tabela 3).

Tabela 3. Saradnja sa školskim pedagogom - upoređivanje obzirom na dob (F-test).

Table 3. Cooperation with the school pedagogue - comparison with regard to age (F-test).

Parametar	N	df	F	Sig.
SŠPRZ	700	4	4,080	,003

Agenda: SŠPRZ-saradnja školskog pedagoga/psihologa i roditelja (zbirno); N-ukupan broj ispitanika; df- broj stepena slobode; F i Sig.- vrijednost F-testa i njegova značajnost.

Ispitanici starosti od 30-35 godina statistički se značajno razlikuju od ispitanika starosti od 36-45 godina i iznad 55 godina starosti. Razlike su utvrđene i između ispitanika starosti od 46-55 godina i onih iznad 55 godina starosti. Između ostalih ispitanika razlike nisu statistički značajne (Tabela 4). Prema tome, zaključujemo da nije potvrđen drugi dio hipoteze da *statistički značajna razlika u percepciji roditelja učenika osnovnih škola na području Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja roditelja i mjesto stanovanja, ne postoji.*

Tabela 4. Saradnja školskog pedagoga/psihologa i roditelja – upoređivanje obzirom na dob.

Table 4. Cooperation between the school pedagogue/psychologist and parents - comparison by age.

	DOB	MD	SE	SIG.
Manje od 30 godina	30-35 godina	,198	,107	,064
	36-45 godina	,020	,101	,845
	46-55 godina	,090	,108	,408
	Iznad 55 godina	-,196	,145	,178
30-35 godina	manje od 30 godina	-,198	,107	,064
	36-45 godina	-,179*	,057	,002
	46-55 godina	-,108	,069	,243
	iznad 55 godina	-,394*	,119	,001
36-45 godina	manje od 30 godina	-,020	,101	,845
	30- 35 godina	,179*	,057	,002
	46-55 godina	,070	,060	,243
	Iznad 55 godina	-,216	,114	,059
46-55 godina	manje od 30 godina	-,090	,108	,408
	30-35 godina	,108	,069	,118
	36-45 godina	-,070	,060	,243
	iznad 55 godina	-,286*	,121	,018
Iznad 55 godina	manje od 30 godina	,196	,145	,178
	30-35 godina	,394*	,119	,001
	36-45 godina	,216	,114	,059
	46-55 godina	,286*	,121	,018

Agenda: MD –razlika aritmetičkih sredina; SE- standardna greška; SIG.- statistička značajnost - postoji statistički značajna razlika na nivou $p < 0,05$.

Vrijednost F-testa i njegova značajnost (Sig.) pokazuju da ne postoji statistički značajna razlika između roditelja s obzirom na stepen obrazovanja o saradnji sa školskim pedagogom/psihologom (Tabela 5).

Tabela 5. Saradnja sa školskim pedagogom/psihologom - upoređivanje obzirom na stepen obrazovanja (F-test).

Table 5. Cooperation with a school pedagogue/psychologist - comparison with regard to the level of education (F-test).

Parametar	N	df	F	Sig.
SŠPRZ	700	4	1,638	,163

Agenda: SŠPRZ-saradnja školskog pedagoga/psihologa i roditelja (zbirno); N-ukupan broj ispitanika; df- broj stepena slobode; F i Sig.- vrijednost F-testa i njegova značajnost.

Iako je F-test pokazao da ne postoje statistički značajne razlike između ispitanika s obzirom na stepen obrazovanja, Post Hoc test je otkrio statistički značajne razlike između ispitanika koji imaju osnovnu školu i onih koji imaju višu stručnu spremu, te između ispitanika sa srednjom stručnom spremom i ispitanika sa višom stručnom spremom. Razlike između ostalih ispitanika nisu statistički značajne (Tabela 6). Analizom dobivenih rezultata zaključujemo da je potvrđen treći dio hipoteze da *statistički značajna razlika u percepciji roditelja učenika osnovnih škola na području Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja roditelja i mjesto stanovanja, ne postoji*.

Iako je F-test pokazao da ne postoje statistički značajne razlike između ispitanika s obzirom na stepen obrazovanja, Post Hoc test je otkrio statistički značajne razlike između ispitanika koji imaju osnovnu školu i onih koji imaju višu stručnu spremu, te između ispitanika sa srednjom stručnom spremom i ispitanika sa višom stručnom spremom. Razlike između ostalih ispitanika nisu statistički značajne (Tabela 6). Analizom dobivenih rezultata zaključujemo da je potvrđen treći dio hipoteze da *statistički značajna razlika u percepciji roditelja učenika osnovnih škola na području*

Sinan, E. i Sređić, D. (2025). Važnost veze između porodice i škole (pedagoga/psihologa). *STED Conference 14*(2), 369-377.

Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja roditelja i mjesto stanovanja, ne postoji.

Tabela 6. Saradnja sa školskim pedagogom/psihologom – upoređivanje obzirom na obrazovanje (LSD).

Table 6. Cooperation with a school pedagogue/psychologist - comparison with regard to education.

STEPEN OBRAZOVANJA		MD	SE	SIG.
OŠ	SSS	-,045	,061	,459
	VŠS	-,221*	,092	,017
	VSS	-,097	,077	,208
	MR i DR	-,096	,140	,492
SSS	OŠ	,045	,061	,459
	VŠS	-,175*	,081	,031
	VSS	-,051	,063	,417
	MR i DR	-,051	,133	,702
VŠS	OŠ	,221*	,092	,017
	SSS	,175*	,081	,031
	VSS	,124	,094	,187
	MR i DR	,124	,150	,407
VSS	OŠ	,097	,077	,208
	SSS	,051	,063	,417
	VŠS	-,124	,094	,187
	MR i DR	,001	,141	,996
MR i DR	OŠ	,096	,140	,492
	SSS	,051	,133	,702
	VŠS	-,124	,150	,407
	VSS	-,001	,141	,996

Napomena: MD –razlika aritmetičkih sredina; SE- standardna greška; SIG.- statistička značajnost - postoji statistički značajna razlika na nivou $p < 0,05$;

Vrijednost F-testa i njegova značajnost (Sig.) pokazuju da postoji statistički značajna razlika između roditelja s obzirom na mjesto stanovanja u percepciji saradnje sa školskim pedagogom/psihologom (Tabela 7). Dakle, možemo zaključiti da nije potvrđen četvrti dio hipoteze da *statistički značajna razlika u percepciji roditelja učenika osnovnih škola na području Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja roditelja i mjesto stanovanja, ne postoji.*

Na osnovu dobivenih rezultata istraživanja zaključujemo da je djelimično potvrđena hipoteza da *statistički značajna razlika u percepciji roditelja učenika osnovnih škola na području Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja roditelja i mjesto stanovanja, ne postoji.*

Tabela 7. Saradnja sa školskim pedagogom/psihologom - upoređivanje obzirom na mjesto stanovanja (F-test).

Table 7. Cooperation with a school pedagogue/psychologist - comparison with regard to place of residence (F-test).

Parametar	N	df	F	Sig.
SŠPRZ	700	9	5,881	,000

Agenda: SŠPRZ-saradnja školskog pedagoga/psihologa i roditelja (zbirno); N-ukupan broj ispitanika; df- broj stepena slobode; F i Sig.- vrijednost F-testa i njegova značajnost.

DISKUSIJA

Provjera pouzdanosti mjerne skale, po procjeni roditelja, od 4 indikatora saradnje školskog pedagoga/psihologa i roditelja, Kronbahovim koeficijentom Alfa ($\alpha = 0,742$), ukazuje na dobru

pouzdanost i unutrašnju saglasnost skale za ovaj uzorak ispitanika, bez obzira na mjernu skalu manju od 10 stavki. Srednja vrijednost korelacije između parova vrijednosti na skali iznosi 0,42 (optimalna između 0,20 i 0,40).

Izračunata aritmetička sredina (M) svih indikatora od 4,18 pokazuje da su faktori saradnje školskog pedagoga/psihologa i roditelja, po procjeni roditelja, veoma važni. Vrijednost standardne devijacije (SD) od 0,77 ukazuje da je rasipanje oko aritmetičke sredine veoma malo, što potvrđuje i koeficijent varijabilnosti (CV) od 18,42% a time i veoma dobru homogenost dobivenih rezultata za ovaj uzorak ispitanika. Ispitanici u većini se slažu i potpuno slažu da su stvaranje radnog ambijenta, zdravo i sigurno okruženje, sredina u kojoj dijete raste i sredina u kojoj se nalazi škola bitni faktori saradnje školskog pedagoga/psihologa i roditelja.

Vrijednost $t = ,548$ i njegova značajnost $\text{Sig.} = ,584$ nam ukazuju da ne postoji statistički značajna razlika u stavovima između roditelja s obzirom na njihov spol u percepciji saradnje sa školskim pedagogom/psihologom. Na osnovu aritmetičke sredine (M) uočavamo da ispitanici muškog spola imaju pozitivnije stavove u odnosu na ispitanike ženskog spola te da je odstupanje od aritmetičke sredine (SD) veće kod ispitanika ženskog spola. Na osnovu dobivenih rezultata zaključujemo da je potvrđen prvi dio hipoteze da *statistički značajna razlika u percepciji roditelja učenika osnovnih škola na području Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja roditelja i mjesto stanovanja, ne postoji*. Vrijednost F-testa i njegova značajnost (Sig.) pokazuju da postoji statistički značajna razlika između roditelja s obzirom na dob o saradnji školskog pedagoga/psihologa i roditelja. Ispitanici starosti od 30-35 godina statistički se značajno razlikuju od ispitanika starosti od 36-45 godina i iznad 55 godina starosti. Razlike su utvrđene i između ispitanika starosti od 46-55 godina i onih iznad 55 godina starosti. Između ostalih ispitanika razlike nisu statistički značajne.

Prema tome, zaključujemo da nije potvrđen drugi dio hipoteze da *statistički značajna razlika u percepciji roditelja učenika osnovnih škola na području Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja roditelja i mjesto stanovanja, ne postoji*. Iako je F-test pokazao da ne postoje statistički značajne razlike između ispitanika s obzirom na stepen obrazovanja, Post Hoc test je otkrio statistički značajne razlike između ispitanika koji imaju osnovnu školu i onih koji imaju višu stručnu spremu, te između ispitanika sa srednjom stručnom spremom i ispitanika sa višom stručnom spremom. Razlike između ostalih ispitanika nisu statistički značajne. Analizom dobivenih rezultata zaključujemo da je potvrđen treći dio hipoteze da *statistički značajna razlika u percepciji roditelja učenika osnovnih škola na području Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja roditelja i mjesto stanovanja, ne postoji*. Vrijednost F-testa i njegova značajnost (Sig.) pokazuju da postoji statistički značajna razlika između roditelja s obzirom na mjesto stanovanja u percepciji saradnje sa školskim pedagogom/psihologom. Dakle, možemo zaključiti da nije potvrđen četvrti dio hipoteze da *statistički značajna razlika u percepciji roditelja učenika osnovnih škola na području Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja roditelja i mjesto stanovanja, ne postoji*.

Na osnovu dobivenih rezultata istraživanja zaključujemo da je djelimično potvrđena hipoteza da *statistički značajna razlika u percepciji roditelja učenika osnovnih škola na području Srednjobosanskog kantona o važnosti saradnje roditelja sa školom (školskim pedagogom/psihologom) s obzirom na spol, dob, stepen obrazovanja roditelja i mjesto stanovanja, ne postoji*.

ZAKLJUČAK

Partnerstvo škole (odgajatelja, pedagoga/psihologa) i roditelja (porodice) je posebno značajno i ono je na tragu usklađivanja odgojnih utjecaja koji su proizvod neposredne komunikacije između škole (odgajatelja, pedagoga/psihologa) i roditelja (porodice) tokom raznovrsnih neposrednih kontakata dvije odgojne sredine. Cilj ovog rada bio je utvrditi izraženost

roditeljskih stavova o važnosti saradnje između škole i roditelja u osnovnim školama na području Srednjobosanskog kantona i razliku roditeljskih stavova u odnosu na spol, dob, stepen obrazovanja i mjesto stanovanja. Rezultati pokazuju da veći dio roditelja smatra da su stvaranje radnog ambijenta, zdravo i sigurno okruženje, sredina u kojoj dijete raste i sredina u kojoj se nalazi škola bitni faktori saradnje školskog pedagoga/psihologa i roditelja. Kada je riječ o razlikama u odnosu na spol, rezultati ovog istraživanja ukazuju da ispitanici muškog spola imaju pozitivnije stavove o saradnji sa školskim pedagogom/psihologom u odnosu na ispitanike ženskog spola. Prema rezultatima poređenja ispitanika različitog uzrasta u njihovim stavovima o važnosti saradnje između škole i roditelja možemo zaključiti da razlike postoje, te da mlađi ispitanici imaju pozitivniji stav o važnosti ove saradnje u školi. Razlika u stavovima postoji i kada je riječ o različitim mjestima stanovanja ispitanika, dok u pogledu stepena obrazovanja razlike nisu pronađene.

Ovo istraživanje bavilo se značajnom i aktuelnom temom u oblasti obrazovanja, jer škola pored obrazovnog procesa učenicima pruža i odgojni aspekt koji u velikoj mjeri zavisi od saradnje školskih službi i roditelja djece. Rezultati ovog rada mogu biti korisni kao inspiracija za buduća istraživanja koja će se baviti ovom tematikom, ali također imaju i praktičnu primjenu. Praktične implikacije rezultata ogledaju se u mogućnosti primjene u oblasti povećanja svijesti stručnih službi škola ali i roditelja o značaju obostrane pozitivne saradnje, ali i u sveobuhvatnom unapređenju funkcioniranja školskih službi.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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THE IMPORTANCE OF THE RELATIONS BETWEEN FAMILY AND SCHOOL (PEDAGOGUE/PSYCHOLOGIST)

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ABSTRACT

The relationship between family and school is always a current topic. The cooperation between family and school implies a traditional spirit. Cooperation in the educational process previously referred primarily to the most basic relations between parents and the school. On the other hand, the partnership of the school (educator, pedagogue/psychologist) and parents (family) is particularly important and it is on the path of harmonizing educational influences that are the product of direct communication between the school (educator, pedagogue/psychologist) and parents (family) during various direct contacts of the two educational environments. Both educational environments carry obligations and responsibilities. From the school climate, the partnership includes (apart from educators and pedagogues/psychologists) the school management, and other members of the collaborative team (if any): social workers and librarians. The main goal of this research is to check whether there is a statistically significant difference in the perception of parents of elementary school students in the Central Bosnia Canton about the importance of cooperation between parents and the school (school pedagogue/psychologist) with regard to gender, age, level of education of parents and place of residence. A total of 700 respondents from the Central Bosnia Canton took part in the survey.

Keywords: family, school, cooperation, partnership.

**XIV INTERNATIONAL CONFERENCE ON SOCIAL AND TECHNOLOGICAL DEVELOPMENT
XIV MEĐUNARODNA KONFERENCIJA O DRUŠTVENOM I TEHNOLOŠKOM RAZVOJU**

VIRTUELNI SVIJET: ILUZIJA ILI SIGURNO UTOČIŠTE ZA DJECU I ADOLESCENTE

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SAŽETAK

Ovaj rad istražuje iskustva djece i adolescenata u vezi sa sigurnošću i nasiljem u virtualnom svijetu, na osnovu podataka prikupljenih putem fokus grupa u kojima je učestvovalo 110 učesnika uzrasta od 6 do 18 godina. Učesnici opisuju svoju svakodnevnu upotrebu digitalnih tehnologija, ističući probleme kao što su nepoštovanje privatnosti, izloženost nasilnom sadržaju, posjećivanje pornografskih web stranica i seksting. Djeca često izvještavaju da se osjećaju sigurno u virtualnom okruženju, dok istovremeno priznaju da dijele lične podatke, pristupaju neprikladnom sadržaju i konzumiraju nasilje kao zabavu. Rezultati ukazuju na to da virtualni svijet sve više postaje prostor bez jasnih granica, gdje su rizici maskirani interaktivnošću i zabavom. Studija ukazuje na hitnu potrebu za sistemskim obrazovanjem o digitalnoj sigurnosti i implementacijom jasnih smjernica za korištenje interneta među djecom i adolescentima.

Ključne riječi: djeca, adolescenti, sigurnost, ekrani, nasilje.

UVOD

Ekrani su postali neizostavan dio svakodnevnog života djece i adolescenata. U posljednjim decenijama, nagli razvoj digitalnih tehnologija drastično je promijenio način na koji mladi komuniciraju, uče i razvijaju se. Iako digitalni alati i online sadržaji mogu imati značajne prednosti – poput brže dostupnosti informacija i novih oblika obrazovanja – sve češće se ukazuje na ozbiljne zabrinutosti u vezi sa njihovim negativnim uticajem na psihološki, emocionalni i socijalni razvoj djece i adolescenata.

Poseban razlog za zabrinutost predstavlja izloženost djece sadržajima koji normalizuju nasilje, potiču sexting, seksualizaciju i objektivizaciju, te narušavaju osjećaj sigurnosti u virtualnim prostorima. Platforme društvenih mreža često služe kao mjesto gdje maloljetnici dolaze u kontakt sa seksualno eksplicitnim sadržajima, neprimjerenim porukama, ali i vršnjačkim i digitalnim nasiljem. Fenomeni poput sekstinga, online predatorstva i dijeljenja neprimjerenih fotografija bez pristanka postaju sve češći oblici narušavanja ličnog integriteta i sigurnosti djece i adolescenata.

Kroz strukturisane razgovore, dobijeni su autentični stavovi, iskustva i razmišljanja djece o tome kako doživljavaju sopstvenu sigurnost u digitalnom okruženju, kako percipiraju nasilje i da li ga uočavaju, sa kakvim sadržajima se susreću i kako ti sadržaji utiču na njihovo ponašanje, emocije i doživljaj sebe, ali i drugih.

Rezultati su pokazali da su djeca i adolescenti nerijetko izloženi seksualizovanim i nasilnim sadržajima, te da često ne posjeduju dovoljno znanja i podrške da se adekvatno zaštite ili da prepoznaju granicu između privatnog i javnog u digitalnom prostoru. Seksting se nerijetko percipira kao "normalan" oblik komunikacije, a koncept pristanka i posljedica dijeljenja intimnih sadržaja ostaje nedovoljno shvaćen među mlađim uzrastima.

Ovim radom nastoji se skrenuti pažnja na potrebu za sistemskom podrškom, edukacijom i regulacijom kada je u pitanju digitalna sigurnost djece i adolescenata. Neophodno je razvijati alate i programe koji će pomoći mladima da razviju kritičko mišljenje, digitalnu pismenost i vještine

Bašić, D. i Ibeljić, E. (2025). Virtualni svijet: Iluzija ili sigurno utočište za djecu i adolescente. *STED Conference 14(2)*, 379-386.

samokontrole, ali i ojačati kapacitete roditelja, nastavnika i donosilaca odluka da prepoznaju i odgovore na rizike koje digitalni svijet nosi.

METODOLOGIJA ISTRAŽIVANJA

U ovom istraživanju korištena je tehnika fokus grupe. Riječ je o kvalitativnoj metodi istraživanja kroz koju moderator može da dođe do određenih stavova, mišljenja, ali i uvjerenja ispitanika o navedenoj temi. Fokus grupa teži slobodnoj formi grupnog intervjua, kroz razgovor u najčešćem slučaju između šest do 12 osoba. U psihologiji metod fokus grupe postaje popularniji i koristi se sve više kao izvor relevantnih podataka koji se ne mogu prikupiti kvantitativnim metodama, jer ova metoda uključuje prikupljanje detalja, specifičnih primjera kao i mogućnost sprovođenja istraživanja na djeci koja nemaju još razvijenu sposobnost čitanja i pisanja.

Cilj istraživanja

Ovim radom cilj je da se istraži kako savremene tehnologije utiču na narušavanje sigurnosti i povećanje nasilja, sextinga, objektivizacije i seksualizacije djece i adolescenata u virtuelnom svijetu.

Učesnici

U ovom istraživanju je učestvovalo 110 djece i adolescenata od šest do 18 godina, koji su raspoređeni u 13 fokus grupa. U istraživanju je učestvovalo 55 osoba ženskog pola i 55 muškog pola, od čega je 73 osnovnoškolskog uzrasta, a 37 srednjoškolskog uzrasta. Grupe su formirane na dva načina: stepen uzrasta učesnika (učesnici su bili istih godina ili godinu razlike) i stepen aktivnosti. (učesnici su bili djeca i adolescenti koji su aktivni i neaktivni u vannastavnim aktivnostima).

Postupak prikupljanja podataka

Postupak prikupljanja podataka zasnivao se na posmatranju verbalnog i neverbalnog ponašanja grupe djece i adolescenata. Sprovedeno je istraživanje u prostorijama četiri škole (dvije osnovne i dvije srednje), a učesnici fokus grupe su učenici istih. Grupe u kojima se provodilo istraživanje podrazumijevalo je učešće djece i adolescenata koji imaju od šest do 18 godina uz pismenu saglasnost roditelja ili staratelja.

REZULTATI I DISKUSIJA

Sigurnost

Učesnici fokus grupa navode da komuniciraju sa osobama koje ne poznaju, a to najviše čine kroz igrice i tako stvaraju svoju virtuelnu socijalizaciju. Takođe, naznačavaju da svoje virtuelne prijatelje nisu upoznali uživo, pojedini bi voljeli, ali nemaju priliku, jer žive u drugoj državi.

Kada govorimo o sigurnosti na društvenim mrežama, učesnici navode da ne prihvataju zahtjeve osoba koje ne poznaju, te ne komuniciraju sa takvima. Manji broj njih ističe da imaju otključane profile, te da može da ih prati ko god želi.

- “Ako se meni sviđa neka fotografija, objaviću je. Nije me briga što postoji rizik da je neko zloubotrijebi. “ - navodi ispitanik (16 godina)
- Sa druge strane, djeca navode drugačije. ” Volim Snapchat zbog svih onih zanimljivih filtera. Uslikam se, pogledam, ali ne šaljem nikad nikome. Objasnili su mi mama i tata da to može da bude opasno. ” - navodi učesnik (10 godina)
- “ Kad smo bili na utakmici, nagovarali su me da robotu sa Snepa pošaljem svoju sliku. Jako malo mi je falilo, to je velika masa djece, uticaj je ogroman, ali nisam poslao. Djeca misle da nisu face, ako ne urade ono što traže drugi, a u stvari ne znaju da im baš to može doći glave.” - navodi učesnik (10 godina)

Kada govorimo o sigurnosti, učesnici fokus grupe takođe navode da virtuelni svijet često zna da bude nesigurno mjesto, pogotovo za osobe koje imaju niži stepen medijske pismenosti i opreznosti. Navode da su ljudi često akteri prevare, gdje se iskoriste lični podaci obično kroz neke

nagradne igre, ulazak na nepoznate linkove, što se manifestuje krađom podataka ili novca. Takođe, učesnici fokus grupe su navodili da uglavnom ne bi otišli da upoznaju uživo osobe koje su upoznali kroz virtualni svijet, dok drugi smatraju drugačije: "Imam druga kog sa upoznao preko igrica. On je iz Sarajeva i upoznali smo se. Desilo se da sam tamo i javio sam mu se, pa sam otišao sa svojim da se upoznam." - navodi učesnik (18 godina)

- "Mom bratu je skoro hakovan nalog i koristili su njegov profil da šalju loše poruke drugima. Sve je prijavljeno policiji, ali nisu uspjeli da otkriju ko stoji iza tog." - navodi učesnik (13 godina)

Adolescenti navode i da je danas prisutan trend tzv. "dijeljenja profila" između partnera, gdje navode sljedeće: "Danas mladi parovi dijele profile međusobno, tačnije imaju ih prijavljene na oba telefona. Onda se jedno od njih javi sa profila ovog drugog, a osoba koja je sa druge strane komunikacije, uopšte ne zna ko joj se javio. Uglavnoj taj drugi partner ne zna za to, poruke se odmah brišu i drugi partner to ne shvati." - navodi učesnica (14 godina)

Adolescenti navode da konstantno objavljivanje sadržaja na društvene mreže više i nije toliko trend. "Mnoge osobe ne žele da objave post, jer on ostaje na feed-u. Radije postavljaju story koji nestane za 24h." - navodi učesnik (16 godina)

Pozakatelj da virtualni svijet može da bude i veoma nesigurnosti mjesto jeste i sljedeće: "Znajte vjerovatno da su otkrivene Telegram grupe, gdje se dijele nage fotografije djevojčica. Nikad ne znate ko je iz vaše okoline u toj grupi i kako vas može fotografisati bez vašeg znanja, ne mora biti naga fotografija, dovoljno je da ima određenu dozu provokativnosti. Sumnjam na par osoba koje poznajem da su u tim grupama, ali nema neki dokaz. Često su znali da opravdavaju osobe koje su u tim grupama, navodeći da su djevojke krive što se tako obuku i izazovu nekog da ih fotografiše. Meni je najgore što postoje ženske osobe koje ulaze u te grupe, podržavaju i gledaju ta ponižavanja." - navodi učesnica (17 godina)

- "U školi ima dječak kog znam, on uvijek tako šalje te nage fotografije koje dobije ili pronađe. To je njima zabavno. Neki šalju svoje slike da se pokažu, neki skinu sa interneta." - učesnik (13 godina)
- "Naš drug je u 5. razredu poslao tako takvu sliku, to se proširilo dalje i onda je došlo i do učiteljice." - navodi učesnik (12 godina)
- "Navode kako ti vršnjaci obično u takvim situacijama budu odbačeni od grupe i ismijavani."
- "Naš problem je što uvijek mislimo da se to neće nama desiti i sa takvim razmišljanjem nismo dovoljno oprezni u virtualnom svijetu." - navodi učesnik (16 godina)
- "Sjećam se kako je u osnovnoj školi još napravljena grupa u kojoj je ismijavana i vrijeđana jedna djevojka. Nisam željela da budem dio tog, jer ne bih nikad nekom radila ono što ne želim da meni neko radi. Pravili su mimove sa pogrdnim tekstom i to slali dalje. Ta djevojka je srećom bila jaka i to nije negativno uticalo na nju, ali na njemu porodicu jeste, jako teško su se nosili sa tom situacijom. To nije bilo samo online nasilje, prelivalo se i u stvarni život. Znali su nekada i da je tuku. Škola je bila upoznata sa problemom i djevojka je prebačena u drugo odjeljenje, tada se smirila situacija." - navodi učesnica (17 godina)

Još jedan pokazatelj da djeca nekad nisu svjesna svih opasnosti u virtualnom svijetu jeste i sljedeća situacija: "Jednom mi je neka osoba poslala zahtjev, prihvatio sam i počele su da mi stižu poruke i fotografije koje nisu lijepe." - navodi učesnik (11 godina)

Dok se drugi učesnik (11 godina) navodovezuje na sljedeći način: "Nije mi se to nikad desilo, ali ako se desi trebamo screenshotovati, to nam je objasnila nastavnica informatike. Onda možemo prijaviti i zaštititi sebe."

Takođe, pojava koja ozbiljno može da naruši sigurnost djece i adolescenata na društvenim mrežama, jeste dopisivanje sa Robijem - robotom koji kako djeca govore "živi u Snepu". To je zapravo robot sa kojim mogu da se dopisuju na društvenoj mreži Snapchat napravljen kroz vještačku inteligenciju i kako djeca navode on ima odgovore na sva pitanja. "Nekad mu pišem, zanimljivo je i odgovara odmah. Nekad ga pitamo šta znači nešto što smo negdje čuli, pitamo ga i o njemu npr. gdje živi, ko je, postavlja i on nama pitanja, možemo tražiti savjet od njega." - navode učesnica uzrasta devet godina

- “Diskord ima super zajednice za igrice, ali isto tako i puno onih sa mračne strane servera, gdje se šalju neprimjerene slike djece. Te grupe su privatne, treba neko da pošalje link da biste mogli da uđete. Nisam nikad u to ulazio, to jeste negativna stvar virtualnog svijeta i smatram da bi te aplikacije trebale da grade politike rada ka ekstermin korisnicima.” - navodi učesnik (12 godina) te se nadovezuje: “Virtualni svijet nekad može da donese i neko traumatsko iskustvo ili pogrešno naučeno ponašanje.” Govoreći o mnogim opasnostima, nadovezao se da mnogi ulaze na pornografske sajtove možda i iz informativnih razloga: “Nekad se mora naučiti nešto o seksualnosti ljudi i o tom šta je seksualni odnos. Uzeo sam udžbenik iz biologije za 9. razred, tamo je to objašnjeno. Nije detaljno, ima jedna slika, ali je zamućena.”

Učesnik jedne od fokus grupa (12 godina) navodi kako veliku opasnost po djecu predstavlja YouTube kids, koji svi posmatraju kao nešto bezopasno. “Skoro sam gledao dokumentarni film Mračna strana YouTube kids-a, koji govori o svemu opasnom i neprimjerenom. Često se na YT kids-u izbacuju videi sa nekim junacima iz crtanih filmova, ali u potpuno neprimjerenim radnjama i scenarijima, a sve to zbog zarade.” - navodi učesnik (12 godina)

Nasilje

Adolescenti ističu kako je prisutna velika količina verbalnog i sajber nasilja kroz virtualni svijet. Često blokiraju profile koji im šalju uvredljiv sadržaj ili komentarišu na takav način njihove objave. Takođe, navodi se kako mnoge osobe ne znaju kako da reaguju u ovakvim situacijama.

- “Doživio sam da mi neko vrijeđa članove porodice kao i mene i da mi šalje uvredljive poruke. Blokirao sam taj nalog i više se nije ponavljalo.” - ističe učesnik (16 godina)

Učesnici fokus grupa naznačavaju kako se danas često dešava da je neko predmet ismijanja i vrijeđanja u prepiskama, čak i grupama. Ponekad se napravi grupa u kojoj je predmet komunikacije osoba koja nije član te grupe i tu se ta osoba vrijeđa i komentariše. Takođe, učesnici navode da se lošije osjećaju kada su predmet ismijavanja, a kada su oni uključeni u nešto tako, to se ponekad doživljava kao vid zabave.

- “Smatram da su savremene tehnologije u velikoj mjeri kod mnoge djece probudile veću količinu agresivnosti i zato je više nasilja, jer je sve postalo normalno.” - navodi učesnik (17 godina).
- “Poznate ličnosti su još više izložene govoru mržnje, jer je veća pažnja usmjerena na njih, ali do se dešava i nama.” - navodi učesnica (16 godina).
- “Recimo dešava se u komunikaciji između momka i djevojke da jedna strana uporno odbija drugu npr. djevojka momka, ne uspostavi se neka veza između njih i taj momak najstrašnije izvijeđa djevojku, samo zato jer mu je rekla ne.” - navodi učesnica (17 godina). Takođe, učesnici navode da mladi ljudi sad i ne kriju svoj identitet i da će bez bilo kakve nelagode širiti uvredljive komentare na društvenim mrežama: “Desi se da neko napiše ispod fotografije ružna si, glupa si. Osobe obično brišu te komentare, blokiraju profil zavisi od osobe do osobe.” - navodi učesnica (18 godina).

Učesnici fokus grupa ističu da je nasilje veoma prisutno i kroz Viber grupe razreda ili grupe koje se namjenski prave da bi se neko “prozivao”. “Jednog drugara iz razreda su dvojica vrijeđali. Postavljale su se ružne njegove slike i pravili su se mimovi. Uzmu njegovu sliku za naljepnicu ili meem, a iznad obavezno ubaci neki komentar npr. Jesi li pio vode danas? Glup si. Ako je naljepnica, to se napravi pomoću Rakuten Vibera, to postave na market naljepnica i onda može da ih preuzme bilo ko, ne samo kreator. On je to pokazao mami, mama je došla u školu i onda su to riješili.” - navode učesnici (12 godina)

Seksualizacija i objektivizacija

Seksualizacija čovjeka kroz virtualni svijet je veoma prisutna, a to ističu i učesnici fokus grupe. U velikoj mjeri se objavljuju provokativne fotografije, kroz koje je cilj da se istaknu obline i

mišići i tako zadobije pažnja šire zajednice. Nerijetko se dešava da adolescenti šalju vlastite seksualne fotografije, a kao razlog navode potrebu da udovolje parteru i njegovim/njenim zahtjevima.

Ipak učesnici smatraju da sebe znatno više seksualizuju i objektivizuju osobe koje imaju i finansijsku korist od toga i na taj način se teže zaustavljaju i ne posmatraju to kao nešto dobro ili loše, nego kao vid zarade.

Pak sa druge strane, učesnici su svjesni da mnoge osobe danas seksualizuju i objektivizuju sebe zbog vlastite nesigurnosti i želje za pažnjom, što daje u korisnicima tog online sadržaja stvara uvjerenje da nisu dovoljno dobri, jer su te osobe sa druge strane ekrana "savršene". - navodi učesnica (17 godina)

"Često se zna desiti da se u društvu komentariše neka djevojka, odnosno njene obline i da drugi u društvu odmah znaju o kome je riječ, ne mora se izgovoriti njeno ime." - navodi učesnica (18 godina)

"Postavljaju se parametri kako neko treba da izgleda, to ponekad ode u krajnost i poznajem djevojke koje su tako razvile anoreksiju ili bulimiju." - navodi učesnica (18 godina)

Kroz razgovor na fokus grupama, učesnici ističu da se danas mnogo dešava tzv. sexting, tj. slanje nagih fotografija kroz online kanale komunikacije, jedna učesnica je odlučila da podijeli svoje lično iskustvo, a ono glasi: "Bila sam dijete, imala sam 14 godina i to je bilo uzajamno, gdje je on meni slao, a ja njemu. On je poslao dalje, a ja nisam. Kad sam shvatila šta sam uradila i šta se desilo, nazvala sam mamu i rekla šta se desilo. Srećom imam otvoren odnos sa svojim. Zajedno sa mamom i tatom sam otišla u policiju. Tu sam saznala sve kako se kome slalo, gdje sam shvatila da mi mnogi nisu prijatelji i da su mi radili iza leđa. Prošlo je i naučila sam lekciju. To ne bih ponovila zbog neugodnosti koju sam doživjela, ali imam i mlađu sestru i nisam željela kad ona dođe u školu da joj neko kaže, e ti si njena sestra. Sama sam prošla kroz taj proces, dobra stvar iz tog je što sam stvorila sebe, svoje samopouzdanje sam digla i bila sam svjesna okej, uradila sam to, ali idem dalje, mnogi propadnu. Znalo se desiti da neko uperi prst u mene i kaže, eno je. Da, eto me i šta ćemo sada, to sam odgovorila jednoj osobi. Ljudi su očekivali da ću se povući, ali znala sam da od toga nemam ništa." - navodi učesnica fokus grupe (17 godina)

Učesnici se nadovezuju na ovu ispovijest, te navode da je veoma bitno da neko ostane stabilan i traži podršku.

Sa druge strane, tzv. sexting je u uzrastu rade adolescencije postavio vrsta trenda i zabave, a učesnici fokus grupa navode sljedeće: "Vjerujte da se danas te fotke samo onako šalju i kad se ne traže." - navodi učesnica (14 godina) "Nage fotografije su se počele slati svima, ne samo jednoj osobi sa kojom je taj neko u vezi. To je postala zabava i vid humora." - navodi učesnik (13 godina). Učesnici fokus grupa navode da su svjesni da ta zabava nekad ode predaleko i da to ne podržavaju, a jedan od primjera koji su naveli je sljedeći: "Puno takvog sadržaja se šalje u grupe na Discordu. Tu nije potreban pravi identitet, možete da se zovete kako želite. Tako je jedan YouTuber na Discordu maloljetnicima slao nage fotografije, eksplicitne videoe. Problem je što postoje takve platforme, gdje nisu potrebni lični podaci i jako je teško otkriti ko stoji iza naloga." - navodi učesnik (13 godina).

"Drug je u grupu našeg razreda, mi smo 6. razred, poslao neku sramotnu fotografiju. Zna se to desiti." - navodi učesnica (11 godina), a druga učesnica istog uzrasta se navodovezuje: "Kada smo bili kod učiteljice, kada smo bili u školi u prirodi na Jahorini, znam da su neki dječaci to gledali i slali." Na pitanje šta misle zašto to nije dobro za njih, odgovaraju sljedeće: "Može da sazna učiteljica, biće problema, dobićemo sniženo vladanje, a i djeca smo, ne treba da gledamo nešto tako." Ova tvrdnja potvrđuje da ovaj uzrast još uvijek nema razvijeno kritičko mišljenje, nego zaključuju na konkretnom nivou, a konzumiranje ovakvog sadržaja onda ima još štetniji efekat po njih.

Određena grupa učesnika ističe da ne osjeća saosjećajnost niti pruža podršku osobama koje prolaze kroz težak period usljed razotkrivanja slanja nagih fotografija. "Dešava se da djevojka momku pošalje sliku, on pošalje drugu, drug svom drugu i to se tako širi. Dešava se često, kad tad dođe do škole i roditelja. Te osobe prožive svašta, budu loše, ali nije mi ih žao. Baš me briga, ne zanima me. Ovaj ko dijeli, on je kao faca, još mu drugi govore hvala brate, kad im pošalje. Ne

možeš to sebi uraditi. Ko želi pažnju, neka je traži na drugi način. Ljudi postaju baš nisko moralni.” - isticalo je nekoliko učesnika uzrasta od 14 do 15 godina

Takođe, učesnica fokus grupe (12 godina) navodi sljedeće: ” Na TikToku imate preporuke kako neko treba da izgleda i koliko ima kg. Npr. osoba koja je visoka 160 cm treba da ima oko 45kg.” Na pitanje, da li su to vidjeli na profilima nekih doktora ili nutricionista, učesnici odgovaraju da su to neki sasvim obični profili.

Adolescenti su svjesni da se u velikoj mjeri danas ljudsko tijelo seksualizuje i objektivizuje, ali isto tako ističu da mnogi odolijevaju tim trendovima. “ Znam ko sam, nema potrebe da me neko posmatra kroz moje obline i ne želim da to potenciram na društvenim mrežama. ” - navodi učesnica (14 godina).

- “ Danas se slike puno fotošopiraju, a sve zbog pažnje i da bi neko rekao u kako dobro izgleda. Ta iluzija se sruši čim se ta osoba vidi na hodniku škole, gdje se vidi da ne izgleda kao na fotografiji. ” - navodi učesnica (15 godina).
- “ Korištenju Photoshop-a su mnogo doprinijele poznate ličnosti, posebno žene, koje time pokazuju i svoju nesigurnost i veoma nisko samopouzdanje. Ne kažem popravim i ja svjetlost, boje, ali ne mijenjam lični opis. ” - navodi učesnica (18 godina).

ZAKLJUČCI

Zaključuje se da djeca i adolescenti koriste ekrane na pozitivan, ali i negativan način, sastavni su dio njihovog života, a veoma često ne postoji granica između stvarnog i imaginarnog svijeta, te se ovi međusobno integrišu. Baš zato, povećan je stepen nasilja, narušene sigurnosti, sextinga, seksualizacije i objektivizacije kroz ekrane.

Istraživanje u sklopu fokus grupa je pokazalo da djeca i adolescenti često nisu svjesni opasnosti koje postoje u virtualnom svijetu, jer ga često poistovjećuju sa realnim, te tako rijetko vode računa kakve privatne informacije i fotografije dijele, prihvataju razne kolačiće na sajtovima, dijele vlastiti otisak prsta za zaključavanje telefona i komuniciraju sa nepoznatim osobama, a pojedini se čak i upoznaju, što pozitivno kolerira i sa drugim svjetskim istraživanjima. Istraživanje pokazuje da djeca i adolescenti koji komuniciraju s nepoznatim osobama na internetu mogu postati meta cyberbullying-a ili drugih oblika online zlostavljanja, a ponekad i žrtve pokušaja seksualne manipulacije. (Kowalski, 2013) Takođe, istraživanja sugerisu da djeca često nemaju razvijenu vještinu kritičkog razmišljanja u vezi s informacijama koje nalaze na internetu, što ih čini osjetljivim na lažne vijesti, prevarante i druge oblike internetskih prijetnji. (Levine, 2017)

Ipak, ne razmišljaju svi tako. Pojedini učesnici su istakli da ne objavljuju svoje fotografije na društvenim mrežama, ne kominiraju sa nepoznatim osobama i bitne razgovore sa vršnjacima ostavljaju za uživo komunikaciju. Međutim, mnogi adolescenti imaju veliku dozu povjerenja u virtualnom svijetu, toliko da dijele svoje eksplicitne fotografije. Najmlađi zabilježeni uzrast, koji je slao svoje nage fotografije, a poznaju ga učesnici fokus grupe, uradio je to u 5. razredu osnovne škole. U istraživanju je navedeno iskustvo adolescentkinje od 17 godina, koja je podijelila svoju priču o ovoj temi. Društvo često ovu problematiku posmatra veoma površno i razgovor sa djecom počinje i završava se sa sljedećim:”Sramota je.” Mimo osjećaja srama, prilikom dijeljenja intimnih fotografija sebe ili drugih, dijete ili adolescent će se suočiti sa nizom posljedica. Istraživanje rađeno u Libanu ukazuje na to da djeca i adolescenti koji šalju nage fotografije mogu doživjeti emocionalne posljedice, kao što su stid, anksioznost i depresija, posebno ako slike budu širene ili korištene protiv njih. Osim toga, djeca mogu osjećati krivnju i nesigurnost zbog svog ponašanja. (Ybarra, 2004) Američko istraživanje pokazuje da djeca koja postanu žrtve cyberbullyinga, uključujući slučajeve gdje su njihove privatne slike podijeljene bez njihovog pristanka, često pate od smanjenog samopouzdanja, niskog samopoštovanja, i povećane socijalne izolacije. (Kowalski, 2013) Studija iz Amerike ukazuje da su djeca koja šalju nag sadržaj često izložena većem riziku od daljnje eksploatacije, uključujući seksualno iskorištavanje, prijetnje i manipulacije od strane odraslih predatora koji ciljaju na ranjivost mladih. (Michell, 2012) Međutim, učesnici fokus grupa navode kako se nage fotografije nekada šalju, ne radi pažnje i dodvoravanja drugoj osobi, nego radi zabave i to bilo kome. Istraživanje iz 2021. godine pokazuje da kada se sexting koristi kao

Bašić, D. i Ibeljić, E. (2025). Virtualni svijet: Iluzija ili sigurno utočište za djecu i adolescente. *STED Conference 14(2)*, 379-386.

sredstvo zabave, to može ukazivati na to da adolescenti ne prepoznaju ozbiljnost svojih postupaka i da imaju poteškoće u razumijevanju emocionalnih posljedica takvih djela, ali i postojanje tendencije ka poremećaju emocionalne regulacije. (Fletcher, 2021)

Društvene mreže su sa sobom donijele život u eri objektivizacije i seksualizacije čovjeka, te tako tim opasnostima podliježu i djeca i adolescenti, naročito osobe ženskog pola. Učesnici u fokus grupama ističu kako je danas veoma bitno kako neko izgleda, da postoje parametri koliko trebamo da imamo kg, kakve obline i mišiće. Mnogi navode da su svjesni ko su, te da ne teže utopijskoj savršenosti koje serviraju poznate ličnosti, ali i isto tako navode da mnoge djevojčice same sebe seksualizuju kroz provokativne objave, koje su nerijetko uređene u Photoshopu kako bi dobile pažnju i divljenje. Istraživanja dokazuju da seksualizacija na društvenim mrežama dovodi do težnje ka nezdravim fizičkim idealima (Fardouly, 2015), smanjuje samopouzdanje i samopoštovanje (Levine, 2009), te povećava mogućnost stvaranja anksioznosti, depresije (Fink, 2017) i moguća seksualno rizičnih ponašanja (Mitchell, 2007).

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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THE VIRTUAL WORLD: ILLUSION OR SAFE HAVEN FOR CHILDREN AND ADOLESCENTS

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ABSTRACT

This paper explores the experiences of children and adolescents regarding safety and violence in the virtual world, based on data collected through focus groups involving 110 participants aged 6 to 18. Participants describe their daily use of digital technologies, highlighting issues such as disregard for privacy, exposure to violent content, visiting pornographic websites, and sexting. Children often report feeling safe in virtual environments, while at the same time admitting to sharing personal information, accessing inappropriate content, and consuming violence as entertainment. The results suggest that the virtual world is increasingly becoming a space without clear boundaries, where risks are masked by interactivity and amusement. The study points to an urgent need for systemic education on digital safety and the implementation of clear guidelines for internet use among children and adolescents.

Keywords: children, adolescents, safety, screens, violence.

VIRTUELNI UZORI: POZITIVNI ILI NEGATIVNI UTICAJI NA FORMIRANJE IDENTITETA DJECE I ADOLESCENATA?

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SAŽETAK

Ovaj rad istražuje vrste uzora koje djeca i adolescenti formiraju u digitalnom svijetu i njihov uticaj na razvoj identiteta. Kroz fokus grupe koje su obuhvatile 110 učesnika u dobi od 6 do 18 godina, studija je analizirala figure koje učesnici najčešće slijede, uključujući sportiste, muzičare i influencere. Posebna pažnja posvećena je motivacijama iza slijeđenja ovih uzora, kao što su osjećaj pripadnosti, identifikacija s određenim načinom života, humor ili informativna vrijednost sadržaja. Rezultati pokazuju da, iako su djeca često svjesna da virtualni uzori ne predstavljaju stvarni život, ipak im pridaju veliki značaj i formiraju emocionalne veze. Studija naglašava potrebu za jačanjem medijske pismenosti i razvijanjem kritičkog stava prema sadržaju koji oblikuje identitete mladih u digitalnom okruženju.

Ključne riječi: uzori, djeca, adolescenti, društveni mediji, seksualizacija.

UVOD

Ekrani su postali sastavni dio svakodnevnog života djece i adolescenata. U posljednjim decenijama nagli razvoj tehnologije drastično je promijenio način na koji djeca i adolescenti komuniciraju, uče i razvijaju se. Iako su ekrani donijeli brojne prednosti, kao što su lakša i brža dostupnost informacija, poboljšana edukacija, one takođe izazivaju i ozbiljne zabrinutosti u vezi sa njihovim uticajem na psihološki, socijalni i emocionalni razvoj djece i mladih.

Cilj ovog istraživanja je da pruži duboku analizu pozitivnih i negativnih efekata korišćenja savremenih tehnologija i izloženosti ekrana kod djece i adolescenata sa posebnim akcentom na kreiranje virtualnih uzora. Istraživanje je sprovedeno pomoću tehnike fokus grupe, u kojoj je učestvovalo 110 djece i adolescenata uzrasta od šest do 18 godina, sa ciljem da se identifikuju ključni faktori koji utiču na njihov svakodnevni život i razvoj, ali i da se daju odgovori na pitanju ko su im uzori, kako i zašto ih stvaraju. Kroz fokus grupu su dobijeni autentični stavovi, iskustva i misli djece i adolescenata, te se ova tehnika pokazala kao veoma korisna u dobijanju dubljih inspicijesta.

Istraživanja pokazuju da mladi ljudi danas češće biraju upravo medijske figure kao uzore, pri čemu ih privlače popularnost, izgled, komunikativnost i zabavnost (Zivoradović-Ilić i sar., 2023). Takvi modeli ne djeluju samo na površinskom nivou imitacije, već mogu značajno uticati na oblikovanje identiteta i vrijednosti djece i adolescenata. Studije u oblasti moralnog razvoja pokazuju da adolescenti nerijetko biraju poznate ličnosti koje doživljavaju kao moralne autoritete – od muzičkih zvijezda do sportista – pri čemu su dosljednost i karakterne osobine presudne za izbor uzora (Journal of Moral Education, 2022). Istraživanje sprovedeno među korisnicima YouTube-a otkriva da kreatori sadržaja pomažu mladima u procesu izgradnje identiteta tako što nude modele osjećanja, stavova i uvjerenja, ali i pružaju osjećaj pripadnosti i socijalne uključenosti. Fenomen parasocijalnih interakcija posebno je izražen u adolescenciji. Mladi često razvijaju emocionalno značajne veze s poznatim ličnostima, zamišljajući odnose koji, iako jednosmjerni, imaju snažan uticaj na njihovo emocionalno iskustvo i razvoj identiteta (PubMed, 2017). Pritom, istraživanja ukazuju da ovakav oblik „obožavanja“ može biti podstaknut ličnim osobinama poput neuroticizma,

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potrebe za pripadanjem i izbjegavajućeg identitetskog stila (PubMed, 2024). Regionalna i međunarodna istraživanja potvrđuju i dvosmjernost ovih uticaja. S jedne strane, influencersi mogu stimulirati kreativnost, intelektualnu radoznalost i motivaciju za učenjem. S druge strane, prekomjerno oslanjanje na medijske uzore može imati negativne posljedice po etičke vrijednosti, socijalno ponašanje i mentalno zdravlje adolescenata (Heliyon, 2023). Osim toga, faktori poput socioekonomskog statusa i uzrasta značajno oblikuju način na koji mladi definišu influencersa, kao i vrijednosti koje im pripisuju (Zozaya-Durazo i sar., 2023). Ukupno posmatrano, virtualni uzori u vidu influencersa i poznatih ličnosti predstavljaju kompleksan razvojni fenomen. Oni istovremeno mogu biti izvor inspiracije, model za identitetsko oblikovanje i socijalno povezivanje, ali i potencijalni rizik za usvajanje površnih vrijednosti, nerealnih standarda i zavisničkih obrazaca ponašanja. Ovim radom želimo osvijestiti kompleksnost dubinu uticaja savremenih tehnologija na formiranje i uticaj virtualnih uzora na djecu i adolescente, kao i ponuditi preporuke za adekvatnu regulaciju i podršku, koja bi omogućila njihov zdraviji odnos prema digitalnom svijetu, ali i podsticaj da se ekrani koriste u pozitivne svrhe, vodeći se samokontrolom i kritičkim promišljanjem.

METODOLOGIJA ISTRAŽIVANJA

U ovom istraživanju korištena je tehnika fokus grupe. Riječ je o kvalitativnoj metodi istraživanja kroz koju moderator može da dođe do određenih stavova, mišljenja, ali i uvjerenja ispitanika o navedenoj temi. Fokus grupa teži slobodnoj formi grupnog intervjua, kroz razgovor u najčešćem slučaju između šest do 12 osoba. U psihologiji metod fokus grupe postaje popularniji i koristi se sve više kao izvor relevantnih podataka koji se ne mogu prikupiti kvantitativnim metodama, jer ova metoda uključuje prikupljanje detalja, specifičnih primjera kao i mogućnost sprovođenja istraživanja na djeci koja nemaju još razvijenu sposobnost čitanja i pisanja.

Cilj istraživanja

Ovim radom cilj je da se istraži kako savremene tehnologije utiču na kreiranje uzora kod djece i adolescenata.

Učesnici

U ovom istraživanju je učestvovalo 110 djece i adolescenata od šest do 18 godina, koji su raspoređeni u 13 fokus grupa. U istraživanju je učestvovalo 55 osoba ženskog pola i 55 muškog pola, od čega je 73 osnovnoškolskog uzrasta, a 37 srednjoškolskog uzrasta. Grupe su formirane na dva načina: stepen uzrasta učesnika (učesnici su bili istih godina ili godinu razlike) i stepen aktivnosti. (učesnici su bili djeca i adolescenti koji su aktivni i neaktivni u vannastavnim aktivnostima)

Postupak prikupljanja podataka

Postupak prikupljanja podataka zasnivao se na posmatranju verbalnog i neverbalnog ponašanja grupe djece i adolescenata. Sprovedeno je istraživanje u prostorijama četiri škole (dvije osnovne i dvije srednje), a učesnici fokus grupe su učenici istih. Grupe u kojima se provodilo istraživanje podrazumijevalo je učešće djece i adolescenata koji imaju od šest do 18 godina uz pismenu saglasnost roditelja ili staratelja.

Diskusija i rezultati

U razgovoru kroz fokus grupe djeca i adolescenti navode razne uzore, koje ne poznaju, a koje gledaju u virtualnom svijetu. Najčešće se ističu sportisti, pjevači, YouTuberi, te navode kako su oni sastavni dio njihovog života, provode mnogo vremena zajedno i samim tim osjećaju povezanost.

- “ Pratim sportiste, jer često objavljuju motivacione objave, poput poruka i fotografija vlastitog izgleda. “ - navodi ispitanik (16 godina)
- “ Mi ne možemo da direktno komuniciramo sa poznatim ličnostima, oni sebe predstavljaju kako žele, zarad popularnosti i zarade. “ - ispitanik (16 godina)

Učesnici fokus grupa uglavnom ističu da su često svjesni tendencije ka manipulaciji koja dolazi do njih kroz virtualni svijet, od strane osoba koje ne poznaju, a postavljaju određene standarde u ovom svijetu. Uviđaju da su sposobni da kritički promisle da li je neko iskren u svojoj komunikaciji i da li lažno predstavlja svoj život i sebe kao savršenstvo. Smatraju da to osobe rade jer žele pažnju drugih, ali i bolju zaradu i veću popularnost.

- “ Volim da pratim poznate ličnosti koje pokazuju svoj život i šta rade u slobodno vrijeme. Taj život je drugačiji od našeg, samim tim, imamo prilikom da doživimo nešto, što inače nikada ne bismo mogli. “ - navodi ispitanik (16 godina)
- “ Djeca često govore roditeljima kako žele duks koji su vidjeli tamo na nekom na Instagramu, kupuju pomahnitalo te sokove što prodaju YouTuberi koji su skupi. To je pokazatelj da se djeca ipak ugledaju na te ljude, iako u realnom svijetu ima super ljudi koji mogu da budu uzori. ” - navodi ispitanik (12 godina)
- “ Npr. Ja ne pratim toliko poznate ličnosti, pratim Zombijanu. Ona ima zanimljiv sadržaj, koji osvijesti i navede nas da nekad razmišljamo o nekoj temi. “ - navodi učesnica (16 godina) A sa druge strane, pokazatelj da nam ekrani nude i niz pozitivnog jeste i sljedeći primjer:”Pratim nove mlade kompozitore, s obzirom da idem u srednju muzičku školu i često imam priliku da nešto naučim ili uvidim na taj način.” - navodi učesnica (17 godina)

Kada govorimo o uzorima koji dopiru do adolescenata kroz muziku, učesnici fokus grupa uglavnom navode kao najpopularnije izvođače pod umjetničkim imenom Voyage i Nucci. Opet sa druge strane, mnogi učesnici su istakli kako uopšte ne prate domaću muzičku scenu, a neki su okrenuti ka domaćoj sceni, ali u polju zabavne i narodne muzike, a ne trepa.

- “ Trenutno primjećujem da sam se stvarno zasitio gledanja sadržaja poznatih ličnosti. Jedan dan sam samo otpratio skoro sve. Sada pratim samo par osoba, manje od 10, koji pružaju sadržaj koji volim da gledam. “ - navodi učesnik (18 godina)

U daljem razgovoru ostali učesnici fokus grupe se poistovjećuju sa ovim iskazom te navode da se i njima dešava da prestaju da prate nekog, jer shvate da ih taj sadržaj ne zanima, da ne dobijaju ništa korisno.

Učesnica fokus grupe (12 godina) navodi kako smatra da svako treba da bude svoj i da je u redu pratiti nekog, jer je zanimljiv ili koristan, ali da ne treba da se trudimo da budemo kao ta osoba. “ Shvatio sam da većina YouTubera želi pratioce, jer žele zaradu. Na nama je da procijenimo šta je ok, a šta nije. Npr. bilo mi je tužno gledati jednog YouTubera koji je koristio životinje da prepada druge, sve zbog pregleda. “ - navodi učesnik (11 godina)

Sa druge strane, učesnici fokus grupa ne mogu da ne zanemare uticaj sada trenutno jedne od najpoznatijih ličnosti pod umjetničkim imenom Desingerica. “Ne znam da li ste čuli za njega, ali on je na jednom nastupu pljunuo djevojci u usta, rendao sir po ljudima, šije patikom ljude u glavu, što je strašno i to je nekom zanimljivo.” - navodi učesnik (12 godina) na šta se nadovezao učesnik iste dobi:”Tako naš drugar u razredu, radi to što radi Desingerica. Uzme patiku i udara druge u glavu.“

Učesnica iste fokus grupe navodi kako će na veću osudu razreda naići osobe koje sa 11 godina gledaju crtane filmove, nego ko imitira Desingericu. “Moja drugarica voli da pogleda neki crtani i uvijek je zezaju kako je djetinjasta, jer smatraju da to nije za naš uzrast, a ustvari oni žele da brzo odrastu.” Drugi učesnik (11 godina) navodi kako mu je tužno da neko trči da bude neko drugi. “Sve je puno bitno iz virtualnog svijeta. Djeca u Beogradu provode sate čekajući da snime auto nekog YouTubera ili pjevača i da to okače. Zaborave na svoj život.” Zatim, učesnica (11 godina) ističe: ” Danas što ne radi niko, što je nešto ekstremnije, što je ružno i sramota to će dobiti pažnju. Sve su manje popularni uspješni sportisti, jer su uložili mnogo truda u to što jesu.” Sa druge strane, na drugoj fokus grupi učesnici (15 godina) navode sljedeće: ” Itekako su još uvijek Novak Đoković, Ronaldo i ostali uzori mladim ljudima i mislim da većina zna procijeniti šta je pravi uspjeh, a šta virtualni.”

- “ Da nadete nekog YouTubera koji kaže čao, sad ću vam ispričati kako su ljudi živjeli prije 100 miliona godina, to nikog ne bi zanima, priznajem ni mene vjerovatno. Jednostavno sve što je drugačije, biće popularno, taman bilo i bolesno. Isto je i sa osobama na koje se

ugledamo. Ne volim Baku Praseta, Desingericu i tako te, sadržaj im je grozan, ali nisu oni loši ljudi. ” - navodi učesnik (10 godina)

- “ Ima jedan YouTuber Simi, gledam ga, vodi me na razna super mjesta, ali nekad se naljutim na njega, jer puno psuje. ” - navodi učesnik (osam godina)
- “ Gledam YouTubera koji se zove Braco Gajić, stvarno mi je zanimljiv i snima originalne klipove. ” - navodi učesnik (sedam godina)

Iz razgovora sa djecom i adolescentima se moglo zaključiti da se vrlo često identifikuju sa osobama koje su veoma popularne u virtualnom svijetu i da se ugledaju na njih, čak stvaraju utisak kao da ih poznaju. “ Desingerica nije loš čovjek. To znam, slušao sam njegovu ženu kako priča kakav je kod kuće i sa djecom. ” - navodi učesnik (devet godina)

ZAKLJUČCI

Na osnovu sprovedenog istraživanja može se zaključiti da djeca i adolescenti koriste digitalne medije i ekrane na različite načine, pri čemu se oblikuju i pozitivni i negativni uzori. Virtualni uzori, bilo da su influencersi, poznate ličnosti ili kreatori sadržaja, svojim uticajem otvaraju prostor i za razvoj i motivaciju, ali i za rizike po mentalno zdravlje i vrijednosne orijentacije mladih. Rezultati fokus grupa pokazali su da mladi često pronalaze uzore „s druge strane ekrana“, što potvrđuje ranije nalaze da adolescenti najčešće biraju osobe iz javnog života – estradne ličnosti i sportiste – kao simbole uspjeha i prestiža (Stepanović, 2009). Iako je istraživanje sprovedeno prije petnaest godina, savremeni kontekst pokazuje da je prestiž postao još važniji kriterijum u odnosu na stvarne sposobnosti i profesionalni uspjeh. Savremena istraživanja dodatno potvrđuju da adolescenti kroz parasocijalne odnose s influencerima i javnim ličnostima razvijaju obrasce ponašanja, vrijednosti i potrošačke navike, pri čemu virtualni uzori često imaju veću težinu od stvarnih osoba iz njihovog neposrednog okruženja (Chen, 2020). Uticaj takvih uzora može biti objašnjen kroz Bandurinu Teoriju učenja po modelu (Bandura, 1977), prema kojoj su posmatranje i imitacija ključni za usvajanje stavova i ponašanja. U digitalnom prostoru, djeca i adolescenti kontinuirano su izloženi sadržajima koji oblikuju njihov identitet i dugoročno utiču na razvoj ličnosti. Horton i Wohl (1956) su još sredinom 20. vijeka, kroz koncept parasocijalne interakcije, pokazali da ovakvi medijski posredovani odnosi mogu postati emocionalno značajni, jer nude osjećaj bliskosti i pripadnosti bez rizika od odbijanja. Danas, novija istraživanja (Akbaş, 2022; Heliyon, 2023) potvrđuju da ovakve veze mogu imati dvostruku ulogu – biti izvor motivacije, inspiracije i socijalne podrške, ali i voditi ka povećanju materijalističkih vrijednosti, digitalnoj zavisnosti i pritisku uspjeha.

Regionalni podaci dodatno osnažuju ove nalaze. Istraživanje u BiH, ukazalo je da su djeca i adolescenti redovno izloženi promotivnim sadržajima na društvenim mrežama u kojima učestvuju poznate osobe i influencersi, čime se povezuje uticaj uzora s potrošačkim navikama (Boričić i sar., 2023). Analiza stavova generacije Z u regionu Balkana (Srbija, Hrvatska i BiH) pokazala je da mladi internet i medije doživljavaju kao centralni dio svakodnevnog života, što uključuje i način na koji biraju i internalizuju uzore (Perić i sar., 2021). Pored toga, istraživanje sprovedeno među mladima u Hrvatskoj i Turskoj ukazuje da su društvene norme i očekivanja vršnjaka značajan faktor u odluci da se prate influencersi, čime se potvrđuje da izbor virtualnih uzora nije samo individualan, već i socijalno i kulturno uslovljen proces (Marušić i sar., 2024). Shodno tome, virtualni uzori se mogu posmatrati kao nezaobilazan dio savremenog odrastanja. Oni nude prilike za razvoj kreativnosti, kritičkog mišljenja i osjećaja pripadnosti, ali i rizik da se kod mladih učvrste površne vrijednosti vezane za popularnost i prestiž (Zivoradović-Ilić i sar., 2023). Ovi nalazi ukazuju na potrebu da se jača digitalna pismenost i kritičko mišljenje djece i adolescenata, te da se uspostavi balans između virtualnih i stvarnih uzora – porodice, vršnjaka i nastavnika. Time bi se potencijal digitalnog okruženja usmjerio u pravcu zdravog razvoja, socijalnog osnaživanja i ličnog napretka, dok bi se smanjili rizici povezani s nerealnim standardima i zavisničkim obrascima ponašanja.

Uzimajući sve u obzir, može se zaključiti da virtualni uzori predstavljaju nezaobilazan dio savremenog odrastanja. Oni mogu biti izvor inspiracije, razvoja i pozitivnih vrijednosti, ali istovremeno mogu dovesti i do rizičnih obrazaca ponašanja ukoliko dominira naglasak na

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popularnosti, prestižu. Stoga je ključno jačati kritičko mišljenje i digitalnu pismenost djece i adolescenata, te graditi balans između virtualnih i stvarnih uzora – porodice, vršnjaka, nastavnika – kako bi se potencijali virtualnog svijeta usmjerili u pravcu zdravog razvoja i ličnog osnaživanja.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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VIRTUAL ROLE MODELS: POSITIVE OR NEGATIVE INFLUENCES ON THE IDENTITY FORMATION OF CHILDREN AND ADOLESCENTS?

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ABSTRACT

This paper explores the types of role models that children and adolescents form in the digital world and their influence on identity development. Through focus groups involving 110 participants aged 6 to 18, the study analyzed the figures most commonly followed by the participants, including athletes, musicians, and influencers. Special attention was given to the motivations behind following these role models, such as a sense of belonging, identification with a certain lifestyle, humor, or the informational value of the content. The results show that while children are often aware that virtual role models do not represent real life, they still assign them significant importance and form emotional attachments. The study emphasizes the need to strengthen media literacy and to develop a critical attitude toward the content that shapes young people's identities in the digital environment.

Keywords: role models, children, adolescents, social media, sexualization.

EDUCATION
OBRAZOVANJE

TRANSFORMING STUDENT AUTONOMY IN CHANGING EDUCATIONAL CONTEXTS: LEARNING MATERIAL CHOICES FROM THE PANDEMIC ONWARD

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ABSTRACT

During the Covid-19 pandemic, the transition to online learning led to a significant increase in students' autonomy in selecting and using educational materials. A survey involving 832 higher education students collected data on their preferences regarding types of learning materials, their perceived usefulness, and various aspects of their learning experiences during the pandemic. The analysis also examined the influence of factors such as study modality (traditional, online, and blended), gender and year of study. The findings revealed clear patterns in students' independent selection and evaluation of educational resources, indicating an increased capacity for self-directed learning during crises. Students reported that, despite altered working conditions, they regularly attended classes, had suitable working conditions, and recognized the significant potential of distance learning. Nevertheless, despite recognizing the benefits of distance learning, approximately 60% of students would still prefer not to adopt it as the sole mode of instruction. In the current context of socio-political challenges frequently disrupting traditional teaching processes, the continuity of learning habits is a relevant question. This paper aims to present the pandemic-era learning experience as a foundation and potential direction for developing future teaching models emphasizing student autonomy and flexible use of educational materials.

Keywords: student autonomy, distance learning, learning materials, higher education.

INTRODUCTION

The Covid-19 pandemic brought about an unprecedented shift in higher education, forcing institutions worldwide to transition rapidly from traditional classroom settings to online modes of instruction (Bozkurt & Sharma, 2020). This transition was not only a logistical and technological challenge but also a pedagogical one, requiring both educators and students to adapt quickly to new learning environments. One of the most significant changes observed during this period was the increased autonomy of students in navigating their educational experience (Hassan et al., 2021; Stevanović et al., 2021). Faced with new circumstances, students were required to take greater responsibility for selecting, accessing, and utilizing learning materials that suited their needs and preferences (Stevanović et al., 2023).

This context provided a unique opportunity to examine how students develop self-regulated learning habits when formal structures are disrupted. While previous researches (Taranto & Buchanan, 2020; Zimmerman & Schunk, 2011) highlights the importance of autonomy and self-regulated learning in developing lifelong learning skills, the pandemic offered a direct insight into how such autonomy emerges and evolves in response to crisis (Stevanović et al., 2021; Stevanović et al., 2023). It became particularly important to explore which types of educational resources students found most useful, how they assessed their own learning conditions, and whether demographic and contextual factors, such as learning environments, gender, and year of study influenced these patterns.

The present study explores the online learning experiences of 832 students from two Serbian universities during the Covid-19 pandemic. Special attention is given to the ways in which students selected and evaluated learning resources, as well as to their overall engagement in online learning environments. In addition to examining students' general perceptions and participation, the study considers how these experiences were shaped by their prior learning environment (traditional, blended, or online), gender, and year of study. By doing so, it aims to shed light on the long-term implications of the pandemic for student agency, resource use, and preparedness for future online education.

To guide this investigation, the study addresses two key research questions:

How did students experience online learning during the Covid-19 pandemic in terms of participation, perceived potential, willingness to adopt it in the future, and access to learning resources, and how did these experiences differ based on their prior learning environment (traditional, blended, or online), gender, and year of study?

Which resources did students rely on during the Covid-19 pandemic, which of them were perceived as most useful, and how did these choices differ depending on students' prior learning environment, gender, and year of study?

The first research question focuses on how students experienced online learning during the Covid-19 pandemic, including how students see their level of participation, access to learning resources, perceptions of the potential of online education, and their willingness to adopt this mode of instruction in the future. The second question explores which learning resources students used, which ones they found most useful, and how their choices varied. Both questions are examined in relation to students' background characteristics, including their previous learning environment (traditional, blended, or online), gender, and year of study, in order to understand how these factors influenced their engagement with and attitudes toward online learning.

LITERATURE REVIEW

Transition to Online Learning During the Covid-19 Pandemic

The rapid shift to online education during the Covid-19 pandemic has prompted numerous studies examining how students adapted to new modes of learning and which resources they relied on during this period. Understanding the broader context of e-learning development and students' perceptions is essential for interpreting the impact of this transition. Over the past decades, various forms of distance education have been developed alongside traditional instruction. Initially relying on correspondence, telephone, and television (Hannay & Newvine, 2006), distance education gradually evolved into online learning, in which the entire educational process takes place via the internet (Bates, 2005). The Covid-19 pandemic significantly accelerated the adoption and development of online learning, prompting widespread use of digital tools for both communication and assessment (Stevanović et al., 2021). Research has shown that students with advanced technological competencies perceived the transition to online learning during the pandemic as relatively smooth and non-threatening (Radha et al., 2019). These findings are consistent with the results of a study by Ali et al. (2019), which involved approximately 700 students who engaged in various forms of e-learning. The participants largely perceived e-learning as user-friendly, time-efficient, and cost-effective. Similarly, Baber (2021) found that students in South Korea successfully adapted to online education during the pandemic, indicating that the shift from face-to-face (F2F) to virtual learning was not met with significant resistance. While the pandemic had a short-term disruptive impact on educational institutions and teaching staff, many studies emphasize the role of student motivation in the success of e-learning environments. Although initial motivation levels tend to be high, they often decline over time. The absence of face-to-face interaction in fully online environments further complicates the challenge of sustaining motivation (Samir et al., 2014; Harandi, 2015). A study conducted in Libya during the Covid-19 pandemic investigated students' attitudes toward e-learning and highlighted both the benefits and the limitations of this approach. Students reported that learning in an electronic environment offered several advantages, such as reduced costs and improved access, and served as an effective alternative to in-person education during the health crisis. However, they also identified significant

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challenges, including the need for better technical and financial support, staff training, adequate infrastructure, digital literacy, and professional development. Notably, while students acknowledged that e-learning contributed positively to their learning experience, they perceived it as shifting more responsibility onto them, while reducing the workload for faculty. The most prominent barrier cited in this context was the poor quality of internet services during the pandemic (Maatuk et al., 2021). Taken together, these studies highlight that while students generally viewed online learning as a viable and even advantageous alternative, the effectiveness of this mode of education is closely linked to prior digital experience, available infrastructure, and sustained motivation throughout the learning process.

Although blended learning, an approach that combines face-to-face teaching with online components, has received increasing attention in recent years (Toptaş and Öztop, 2021; Fitri and Zahari, 2019), the Covid-19 pandemic created an exceptional situation in which many institutions were required to shift directly from traditional classroom instruction to fully online formats, while a number of institutions managed to transition from traditional to blended learning. Blended learning is generally associated with greater flexibility, opportunities for self-paced learning, and higher levels of student engagement (Setyaningrum, 2018). These characteristics have been shown to support student motivation and persistence (Anthony et al., 2022), as well as promote more effective knowledge acquisition (Božić et al., 2021). Although the present study does not focus directly on blended learning, it is important to acknowledge that during the pandemic, some studies emphasized the value of preserving certain elements of face-to-face interaction within digital learning environments. For instance, Aboagye et al. (2020) reported that the combination of traditional and online teaching had a positive effect during the transition period brought on by Covid-19. Similarly, Mali and Lim (2021) found that students viewed blended learning more positively during the pandemic but still preferred face-to-face learning in non-pandemic circumstances. Although blended learning is often praised in theory as a modern and flexible instructional model, some studies suggest that students perceive certain aspects of virtual learning environments as limited, especially in terms of interaction, group work, and access to complex technical content (Bentley, 2012; Turner, 2015). Numerous authors have highlighted the challenges students faced when transitioning from face-to-face to blended or online formats. These include reduced opportunities for interaction with instructors, weaker dynamics in group work, limited peer collaboration, lower levels of classroom engagement, and fewer chances to ask questions particularly in technically demanding subjects (Concannon et al., 2005; Robson and Greensmith, 2009; Selwyn, 2016). In addition, qualitative evidence shows that face-to-face instruction is perceived as socially richer and more supportive, as social aspects expected in a physical classroom are not easily replicated in digital learning environments governed by netiquette and asynchronous formats. On the other hand, some researchers argue that the sudden and large-scale shift to online and blended learning during the pandemic created opportunities for innovation in higher education. Sangster (2020) notes that the pandemic accelerated the development of more flexible teaching formats, such as pre-recorded lectures, which may contribute to the long-term transformation of educational practices (Bettis, 2020; Fogarty, 2020; Sangster et al., 2020).

The literature suggests that while many students adapted successfully to online learning during the Covid-19 pandemic, others encountered difficulties related to motivation, interaction, and technological access. Although blended learning offers certain pedagogical advantages, it does not fully replicate the social and academic benefits of traditional face-to-face instruction. These findings underscore the importance of contextual factors in shaping students' learning experiences and form a basis for further investigation into how students with different prior learning backgrounds navigated the transition to fully online education. The present study specifically examines how previous experience with traditional, blended, or fully online learning influenced students' adaptation to new educational circumstances during the pandemic. It explores whether students attended classes and had access to appropriate learning resources, their readiness to adopt similar instructional formats in the future, and their perceptions of the potential of online learning as a long-term educational model.

Self-Regulated Learning and the Use of Learning Resources in Online Education

Self-regulated learning (SRL) refers to students' ability to actively guide and manage their own learning through a set of cognitive, motivational, and behavioral strategies. These include setting learning objectives, drawing on prior knowledge, seeking out relevant content, and continuously monitoring and adjusting their learning process based on ongoing reflection and evaluation (Zimmerman, 1990; Pintrich, 2004; Zimmerman and Schunk, 2011). When faced with difficulties or uncertainty, self-regulated learners are also more likely to seek support and modify their strategies to improve outcomes. Researches have consistently shown that self-regulation plays a vital role in the success of students in online learning environments, which typically offer greater flexibility but demand higher levels of autonomy (Broadbent and Poon, 2015; Jia, 2021; Xu et al., 2022). Unlike traditional classroom settings, online learning requires students to take responsibility for organizing their time, managing their progress, choosing learning resources, and staying motivated without direct supervision (Artino, 2007; Dumford and Miller, 2018). In such contexts, learners who can independently plan, monitor, and evaluate their study process are more likely to thrive (Mou, 2020; Mou, 2023).

An important but sometimes overlooked component of self-regulated learning is the strategic selection and use of learning resources. In online settings, students are typically presented with a wide array of digital materials—such as recorded lectures and exercises, textbooks, scripts, interactive e-learning content, PowerPoint presentations, and various documents, as well as platforms and instructional materials independently found online (Martin & Bolliger, 2018). The effectiveness of their learning often depends on how well they can navigate this abundance, assess the relevance and quality of materials, and incorporate them into their learning routines (Frontiersin review, 2021). Efficient use of resources thus becomes both a skill and a form of self-regulation, enabling students to adapt content to their personal needs, learning styles, and academic goals (Broadbent & Poon, 2015).

This study aims to explore which types of resources students found most valuable during the shift to online education caused by the Covid-19 pandemic. It also investigates the extent to which students participated in online classes and how their engagement with learning materials influenced their readiness to embrace this mode of instruction in the future. Finally, it examines how students perceived the long-term potential of online education, viewed through the lens of their self-regulated learning practices and their ability to meaningfully use available learning resources.

METHODOLOGY

Participants

There were 832 participants in this study, students from two universities in Serbia (626 participants from Faculty of Science, University of Novi Sad (UNS) and 206 participants from the faculties of Belgrade Metropolitan University (BMU)). The demographic data are shown in Table 1.

Table 1. Demographic data.

Category		N	%
Gender	Male	304	37%
	Female	528	63%
University	UNS	626	75%
	UM	206	25%
Learning environments	Traditional	633	76%
	Online	166	20%
	Blended	33	4%
Year of study	First	261	31%
	Second	198	24%
	Third	185	22%
	Forth	188	23%

Instruments and Procedure

The data for this study were collected using a structured questionnaire, which was distributed via email at the end of the academic semester. Participation was voluntary and anonymous. The questionnaire consisted of three sections. The first section gathered demographic information, including gender, university affiliation, prior learning environment (traditional, blended, or online), and year of study. The second section focused on evaluating students' experiences with online learning, including items related to attendance, access to learning conditions, perceived potential of online education, and preferences for future use. Responses were rated on a six-point Likert scale ranging from 1 ("strongly disagree") to 6 ("strongly agree"). The third section asked students to indicate which types of additional learning resources they had used during online learning by selecting from a predefined list (checkbox format). Scale reliability was assessed using Cronbach's alpha, and the overall internal consistency was acceptable ($\alpha = .795$).

To better understand students' engagement with online learning, four key dimensions were assessed: Attendance, Conditions, Potential, and Preferences. Attendance refers to the extent to which students reported regularly following online classes during the pandemic. Conditions captures students' opinion about access to essential technical resources, such as a computer and a stable internet connection, needed for effective participation in online education. Potential reflects students' beliefs about whether online learning can serve as a valid substitute for traditional classroom instruction. Finally, Preferences indicate students' openness to fully transitioning to online learning in the future.

Additionally, students were asked to evaluate the usefulness of specific types of learning materials they encountered during online instruction. The aim was to explore patterns in resource selection and to assess students' evaluations of the usefulness of specific materials in supporting their learning. Students rated five types of resources based on their perceived usefulness using a six-point Likert scale. These included: complete online video recordings of lectures and exercises (U_VM), textbooks, scripts, and PDF materials (U_PDF), interactive digital content for e-learning (U_INM), PowerPoint presentations from lectures and exercises (U_PP), and various documents and instructional materials independently found online (U_NET). This section of the questionnaire was designed to capture not only students' preferences, but also their perceived level of trust in and reliance on different forms of learning support during the pandemic.

Data Analysis

Data were analyzed using SPSS with nonparametric statistical tests due to non-normal distribution of data. The Mann-Whitney U test was applied for two-group comparisons, and the Kruskal-Wallis test for three or more groups, followed by post hoc analysis.

RESULTS

In line with the research questions, the results and discussion are organized into two main sections: Students' Experiences with Online Learning, and Selection and Evaluation of Educational Materials.

Students' Experiences with Online Learning

Student responses related to Attendance, Conditions, and Potential indicate generally high levels of engagement in online learning, as well as widespread access to the necessary technical requirements, such as a computer and internet connection (see Figure 1). In addition, students recognized the value and potential of online learning as a meaningful educational approach. However, when it comes to Preferences for fully transitioning to online learning, notable differences were observed depending on students' prior learning environments (see Figure 2). Those with experience in online or blended learning expressed a greater openness to continuing their education in a fully online format, while students with traditional learning backgrounds tended to be more hesitant.

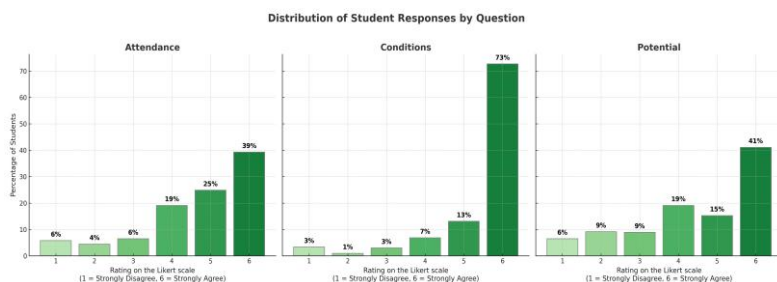


Figure 1. Distribution of students' responses by question.

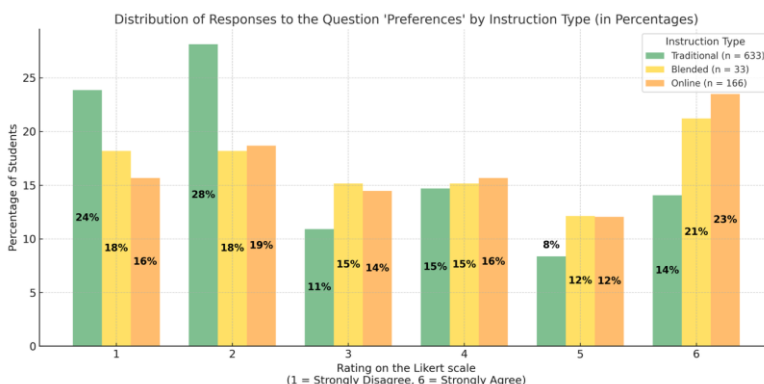


Figure 2. Distribution of students' responses by question "Preferences" by type instruction. χ^2

The results of the Kruskal–Wallis tests examining differences in students' distance learning experiences across the three learning environments (Traditional, Online, and Blended) are presented in Table 2. Significant differences between the three subgroups were evident in the Preferences category ($H = 17.598, p = .000$), with a mean rank of 397.35 for traditional students, 480.05 for online students, and 464.21 for students in the blended subgroup. In the other categories (Attendance, Potential and Conditions), no statistically significant differences were observed between the subgroups.

The post hoc (pairwise comparisons) test (conducted for Preferences, as it was the only category showing a significant result) indicated that there was a statistically significant difference only between the traditional and online groups, with a significance level of $p = .000$.

A statistically significant gender difference was found in the Attendance variable, with female students reporting higher levels of regular participation in online classes compared to male students ($U = 73064, p = 0.02$). Although overall attendance was rated highly across all study years, results of the Kruskal–Wallis test indicated a statistically significant difference between groups ($H = 23.84, p < 0.01$). Post hoc comparisons using the Bonferroni correction revealed that second-year students reported significantly higher attendance compared to both first-year and fourth-year students ($M_I = 4.64, M_{II} = 5.04, M_{IV} = 4.30; p = 0.014$ and $p < 0.01$, respectively).

Table 2. Analysis of the correlation between the learning environment and online learning

Category	Mean Ranks			Kruskal-Wallis		
	Traditional	Online	Blended	χ^2	Df	p Value
Attendance	423.36	391.82	409.02	2.509	2	.285
Potential	426.00	381.01	412.76	5.028	2	.081
Preferences	397.35	480.05	464.21	17.598	2	.000
Conditions	413.74	431.17	395.67	1.550	2	.461

Notes: χ^2 = Chi square; Df = Degree of freedom

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In terms of Potential, students across all years generally rated online learning positively (Fig. 1). However, a statistically significant difference was observed between groups ($H = 10.36, p = 0.02$). First- and second-year students expressed slightly more favorable perceptions of online learning potential compared to students in higher years, particularly those in the fourth year ($M_I = 4.62, M_{II} = 4.63, M_{III} = 4.51, M_{IV} = 4.22$). Bonferroni-adjusted comparisons confirmed significant differences between the first and fourth year ($p = 0.02$) and between the second and fourth year ($p = 0.04$).

As for Preferences regarding the future use of online learning ($H = 9.00, p = 0.03$), students in higher years showed greater readiness to fully transition to this mode of instruction. Mean scores increased progressively with each year of study ($M_I = 2.86, M_{II} = 3.14, M_{III} = 3.25, M_{IV} = 3.34$). Statistically significant differences were found between first and fourth year ($p = 0.03$).

Selection and Evaluation of Educational Materials

The results of the Kruskal–Wallis tests examining differences in perceived usefulness of various learning resources among students from different prior learning environments (traditional, online, and blended) are presented in Table 2. In general, all resources were rated as useful, with no statistically significant differences observed between groups for video lectures (U_VM), PDF materials (U_PDF), PowerPoint presentations (U_PP), or independently gathered online materials (U_NET). However, a significant difference was found in the usefulness ratings of interactive learning materials (U_ILE), $\chi^2(2) = 11.239, p = .004$. Post hoc pairwise comparisons using the Bonferroni correction revealed that students with prior experience in online learning rated interactive materials as significantly more useful than students from traditional learning backgrounds ($p = .003$). No significant differences were found between the blended group and the other two groups.

Table 2. Mean Ranks and Kruskal–Wallis Test Results for Perceived Usefulness of Learning Resources Across Learning Environments.

Category	Mean Ranks			Kruskal-Wallis		
	Traditional	Online	Blended	χ^2	Df	p Value
U_VM	412.77	437.68	381.47	2.236	2	.327
U_PDF	412.21	436.51	398.12	1.703	2	.427
U_ILE	403.24	470.90	397.12	11.239	2	.004
U_PP	413.77	432.08	390.45	1.237	2	.539
U_NET	414.77	421.60	424.00	.147	2	.929

Notes: χ^2 = Chi square; Df = Degree of freedom

When asked which educational materials they perceived as the most useful, the vast majority of students reported relying on PDF materials (textbooks, scripts, and lecture notes in PDF format), with 83.17% of respondents selecting this option. This was followed by PowerPoint presentations (59.74%) and interactive digital content (55.41%), indicating that structured and instructor-provided materials were the most commonly used. In contrast, online video lectures were selected by only 31.73% of students, while independently sourced materials from the internet were used by 37.74% of respondents. Notably, a very small proportion of students (2.76%) reported not using any additional resources beyond the standard course content. These findings suggest a clear preference for officially provided and static formats (PDFs and presentations), while more dynamic or self-directed formats such as video lectures or external web-based materials were less frequently used.

Students typically reported using two to three different types of learning resources during online instruction. The most frequently selected materials were PDF documents, interactive learning materials (INM), and PowerPoint presentations (PP). When students selected only two resources, the combination of PDF and PP was most common. Statistically significant differences were found in material preferences across gender and year of study.

Table 3. Student Use of Educational Resources During Online Learning

Educational materials	Number of students (N)	Percentage of students(%)
PDF	692	83,17
INM	461	55,41
PP	497	59,74
LN	264	31,73
NET	314	37,74
N	23	2,76

Notes: PDF - materials (textbooks, scripts, and lecture notes in PDF format), INM - interactive digital materials, PP - PowerPoint presentations, LN - online video lectures, NET- independently sourced materials from the internet and N - not using any additional resources beyond the standard course content.

Female students reported using PDF materials more frequently than male students (86.6% vs. 77.3%), a difference that was statistically significant ($\chi^2 = 11.44, p < .01$). Additionally, students in higher years of study reported using PDF materials more often than those in lower years ($\chi^2 = 18.61, p < .01$). On the other hand, male students reported slightly higher usage of internet-sourced materials and lecture notes, although overall usage of these resources remained relatively low. This difference was also statistically significant ($\chi^2 = 7.16, p < .01$).

DISSCUSSION

The findings of this study show that a significant proportion of students (83%) reported high levels of attendance during online classes throughout the Covid-19 pandemic. Female students indicated more consistent participation compared to their male counterparts. This result aligns with previous research suggesting that female students are often more diligent and consistent in fulfilling academic responsibilities (Verbic et al., 2025). Regarding learning conditions, most students stated that they had adequate access to the technical resources necessary for participating in online learning. This finding contrasts with the results reported by Maatuk et al. (2021), where students expressed dissatisfaction with the conditions for online learning. Such a discrepancy highlights the importance of context, suggesting that the quality of online learning conditions can vary significantly across educational systems. In the present study, no statistically significant differences were found in reported learning conditions across gender, year of study, or learning background, which further suggests that, in the case of Serbia, the basic infrastructural conditions for online learning were met to a satisfactory degree. When asked whether online learning could serve as a substitute for traditional classroom instruction, approximately 75% of students responded positively, with only 6% explicitly rejecting this possibility. Interestingly, younger students were more likely to view online learning as a viable replacement for traditional instruction than older students. This generally favorable view may reflect the overall positive experiences students had with online learning during the pandemic. These findings are consistent with earlier studies that emphasize the adaptability of students and the potential of online education when implemented effectively (Ali et al., 2019; Radha et al., 2019; Baber, 2021). However, even though a majority of students believed online learning could replace traditional teaching, a smaller percentage (around 40%) actually expressed willingness to fully transition to this mode of education. Students who had previously participated in online or blended learning before the pandemic were more open to continuing in that format, while those with exclusively traditional learning backgrounds were more hesitant. This suggests that prior learning experience plays a crucial role in shaping students' readiness to adopt online learning in the future. Interestingly, while younger students perceived online education as having potential to replace traditional learning, they were less willing to make that transition at the time of the study. In contrast, older students showed greater readiness to switch to fully online learning. These findings suggest a distinction between students' cognitive acceptance of online education and their actual preference or readiness to engage in it fully. Although the benefits of online and blended learning have been widely discussed in the literature (Anthony et al., 2022; Božić et al., 2021; Bettis, 2020; Fogarty, 2020; Sangster et al., 2020), students in this study still recognized its limitations. Their reluctance

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to fully embrace online learning, despite acknowledging its potential, aligns with findings from other research (Mali & Lim, 2021; Bentley, 2012; Turner, 2015), which also show that students tend to prefer traditional classroom instruction over fully online formats. In conclusion, the results of this study suggest that while students had adequate access to resources, demonstrated high participation, and expressed belief in the potential of online education, many of them were still not ready to abandon traditional learning environments. This gap between perceived potential and actual preference underscores the complex and multifaceted nature of students' attitudes toward online learning.

When it comes to the selection of learning materials during the Covid-19 pandemic, students most frequently reported that textbooks, scripts, and PDF materials were the most useful, followed by PowerPoint presentations. At first glance, this finding may seem surprising, considering the availability of various interactive and multimedia-based learning materials during this period. However, one possible explanation is that these types of resources had already been widely used in traditional classroom settings. Therefore, students may have simply intensified their use of familiar materials during the shift to online learning. While this interpretation appears plausible, further research is needed to confirm whether previous familiarity directly influenced students' choices during the pandemic. Supporting this assumption, the results indicate that senior students found PDF materials more useful than younger students. This may suggest that more experienced learners, who were already accustomed to this format, continued to rely on it during the transition to online learning. However, additional studies would be necessary to determine whether this preference is driven primarily by habit, prior exposure, or specific learning needs. This trend may also reflect the characteristics of the educational environment in which the study was conducted, where such materials were readily available both before and during the pandemic. Despite the increased availability of video and interactive content, students largely perceived the most value in materials they were already familiar with. Gender differences were also observed, with female students more often rating PDF materials as useful, while male students more frequently identified internet-sourced content as beneficial. This finding could potentially be explained by general patterns noted in previous research, where female students are described as being more diligent and inclined to rely on structured and reliable sources, whereas male students may be more open to exploration and taking risks in learning (Verbic et al., 2025). Nevertheless, these assumptions should be interpreted with caution, and further empirical investigation is required to validate gender-based preferences in online learning resource selection. Although most students selected traditional formats such as PDFs and PowerPoint slides, the results revealed a considerable number of combinations of different educational resources. This indicates that students were actively adapting their learning strategies by drawing on multiple types of materials, reflecting individualized, self-regulated learning practices (Artino, 2007; Dumford and Miller, 2018). Even when relying on resources typically used in face-to-face instruction, students' ability to adjust their resource selection to personal needs suggests the presence of self-regulated learning skills, which have been shown to be important for success in online education (Mou, 2020; Mou, 2023). Future studies could further explore how such resource selection relates to specific dimensions of self-regulated learning in diverse educational contexts.

CONCLUSIONS

The sudden shift to online learning during the Covid-19 pandemic served as a unique opportunity to explore how students respond to new educational challenges and adjust their learning strategies. Findings show that students generally had the necessary technical conditions to participate in online learning and were able to maintain continuity in their studies. While many students recognized the value and potential of online learning, a significant portion, particularly those in the earlier years of study, still preferred traditional formats, reflecting deeply ingrained expectations and learning habits.

These results, including the dominant use of PDF materials and other static content formats, reflect an educational system that continues to favor traditional approaches despite advancements in digital technologies. Within such a framework, students tend to rely on more linear, passive

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forms of learning, even though more interactive and personalized options are increasingly available. Differences in student experiences and preferences based on demographic factors, underscore the importance of more flexible, individualized models of education. As students' progress through their academic journeys, they demonstrate a growing ability to independently choose and evaluate learning resources, pointing to an increasing level of learning autonomy.

These findings underscore the need for higher education institutions to design and implement student-centered approaches that encourage self-directed learning and are adaptable to both expected and unexpected changes. Based on the experience of the pandemic, it is possible to shape an educational system that not only meets contemporary demands but also actively supports the development of competent, self-directed learners equipped for the challenges of the digital age.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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MATHEMATICS FOR FUTURE ENGINEERS: STUDENT ATTITUDES, LEARNING STRATEGIES, AND THE ROLE OF TECHNOLOGY

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ABSTRACT

In engineering education, mathematics plays a key role not only in developing basic numerical competence but also in facilitating the understanding of advanced concepts and the development of critical reasoning. As technological innovation accelerates, particularly with the rise of artificial intelligence and data-driven systems, mathematics becomes increasingly important in engineering education, providing students with the skills needed to engage with complex problems and advanced reasoning. This study examines engineering students' attitudes toward mathematics, their learning approaches, and the role of information technology in the learning process. A questionnaire-based survey was conducted among 269 engineering students from the University of Belgrade and the University of Novi Sad. The results indicate that engineering students generally hold positive attitudes toward mathematics. They tend to prioritize solving tasks over understanding theoretical content, and peer interaction emerges as an important learning resource. The study also explores differences in attitudes based on gender, previously completed courses, and year of study. Findings of this study underscore the importance of aligning mathematics instruction with students' perspectives and learning preferences. The study recommends strengthening theoretical learning through interactive, technology-supported environments that foster deeper mathematical engagement and critical thinking in engineering education.

Keywords: Engineering students, attitudes toward mathematics, engineering education, learning approaches, technology-supported learning.

INTRODUCTION

Mathematics represents a fundamental component of engineering education, forming the basis for analytical reasoning, modeling, and decision-making across a wide range of technical domains (Flegg et al., 2012). Engineering students are routinely required to engage with mathematical concepts not only throughout their academic studies, but also in practical problem-solving and interdisciplinary collaboration in their future professional roles.

Understanding how students perceive the role of mathematics in their education can inform instructional design and contribute to more effective teaching and learning environments. Prior research has shown that student attitudes toward mathematics, self-confidence in their mathematical abilities, and individual learning approaches can significantly influence academic performance and long-term engagement in STEM fields (Ahmed et al., 2012; Kloosterman et al., 2008). Moreover, variations in students' educational backgrounds such as the type of secondary school attended or the number of mathematics courses completed may be reflected in their study habits and learning preferences (Tamar & Kohen, 2022).

The integration of digital technologies into the learning process has also become increasingly relevant. The use of ICT tools, including mathematical software, online platforms, and, more recently, AI-based assistants, offers new opportunities for personalized and flexible learning in mathematics (Guler et al., 2024; Li et al., 2010). However, student engagement with these

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resources often varies, depending on their learning strategies, previous experiences, and perceived usefulness of the tools.

This study aims to explore engineering students' attitudes toward mathematics, their use of information and communication technologies in learning, and their preferred learning strategies. By examining how these aspects relate to variables such as gender, academic year, and educational background, the research seeks to provide insights that can support evidence-based pedagogical improvements in engineering education.

LITERATURE REVIEW

Attitudes towards mathematics

A substantial body of research confirms that engineering students' attitudes toward mathematics exert a decisive influence on both their academic performance and their willingness to engage deeply with the subject. The literature converges on several interrelated themes that shed light on the factors shaping these attitudes.

Many engineering students enter university with limited confidence in their mathematical capabilities, which can immediately constrain their academic performance. Conversely, students who believe in their capacity to master mathematical tasks and who possess strong self-efficacy consistently achieve better results and express more positive attitudes, regardless of their prior preparation (Panaoura et al., 2024; Shamsuddin et al., 2018).

Attitudes are also shaped by the extent to which students recognize mathematics as integral to engineering practice. Those who understand the relevance of mathematical knowledge to solving real-world problems tend to demonstrate greater persistence and interest in learning mathematics. The belief that mathematical tools are essential for engineering tasks strengthens their motivation and engagement (Zavala & Dominguez, 2016; Panaoura et al., 2024).

Empirical studies also point to persistent gender-based differences in students' attitudes toward mathematics. Male students generally report more favorable beliefs about the nature of mathematics and their ability to learn it, while female students are more likely to experience mathematics anxiety. This anxiety has been shown to negatively affect both attitudes and academic performance in STEM fields (Maat et al., 2010; Megreya et al., 2025).

Teaching practices that emphasize the practical applications of mathematics, such as solving authentic engineering problems, have the potential to improve students' attitudes and outcomes. Interventions aimed at boosting confidence, reinforcing the usefulness of mathematics, and providing timely support are particularly beneficial. Such approaches help foster students' interest and motivation, which in turn enhances their engagement and achievement (McDonald & Brooks, 2021; Villar-Sánchez et al., 2022; Shamsuddin et al., 2018).

Finally, research suggests that students' attitudes toward mathematics may change over time. First-year students often begin their studies with relatively positive perceptions, but enthusiasm and confidence can decline as they progress through their programs. This trend highlights the need for continuous support and well-designed instructional strategies that maintain students' interest and reinforce the importance of mathematics in engineering (Villar-Sánchez et al., 2022; Zavala and Dominguez, 2016).

Usage of ICT for learning mathematics

The use of information and communication technologies (ICT) in engineering mathematics education has diversified significantly in recent years, with students employing a variety of digital resources to support different aspects of their learning. Research shows that engineering students rely on digital tools not only for procedural tasks but also for conceptual understanding and self-regulated study paths (Pepin et al., 2021). For example, Kock and Pepin (2018) observed that first-year students drew on secondary school habits and emulated familiar learning strategies when navigating digital and material resources in Calculus and Linear Algebra courses. However, without explicit guidance, this transfer often led to difficulties, emphasizing the need for better support in resource management.

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Digital environments allow for greater flexibility and personalization in learning, accommodating the heterogeneous backgrounds of engineering students. Tools such as online modules, adaptive tutorials, and interactive videos offer students the ability to choose between lecture-based or self-paced content delivery, depending on their preferences and needs (Howard et al., 2018; Pepin et al., 2021). Moreover, dedicated software, including CAS systems and spreadsheet tools, are not only used for computation but also to verify solutions and encourage reflective engagement with mathematical content (Van der Wal et al., 2019).

Nevertheless, the effectiveness of ICT tools depends largely on their pedagogical integration. Studies warn that poorly designed tasks within digital platforms may allow students to obtain correct answers without a genuine understanding of the underlying mathematics, as demonstrated in Kanwal's (2020) analysis of Maxima use within MyMathLab. These findings underscore the importance of aligning technological resources with instructional goals to foster meaningful mathematical activity and support conceptual learning.

Learning habits

Learning habits among engineering students in the field of mathematics show considerable variation, particularly in terms of how students sequence their engagement with theoretical content and problem-solving tasks. While some prefer to begin by tackling exercises and consult theoretical concepts only when necessary, others follow a more structured path, first focusing on understanding the theory before moving on to problems (Havola, 2020). These contrasting strategies reflect broader individual differences that stem from students' previous educational experiences, self-concepts, and expectations. It is common for students to continue using learning methods developed during secondary education, including the order in which they approach content, suggesting a certain consistency in learning preferences over time (Havola, 2020).

Moreover, learning strategies are not static; many students revise their approach as a result of academic setbacks. For example, after underperforming on initial assessments, some adapt by changing the order in which they engage with theoretical and practical material. This type of adjustment highlights the dynamic nature of learning and emphasizes the importance of identifying which strategies best support different learner profiles within engineering education (Havola, 2020).

However, for many students, merely having access to content in a general format may not be effective (De Melo et al., 2014; Maric et al., 2015). In addition to traditional lectures, instructors can support deeper learning by offering enhanced guidance, such as advance organizers, summaries, repetitions, and targeted questioning (Gehlen-Baum & Weinberger, 2014). Ultimately, there remains a gap in our understanding of undergraduate study behaviors, as few factors beyond non-cognitive traits have proven explanatory power (Delaney et al., 2013).

Methodology

Participants

The study included a total of 269 undergraduate engineering students from two institutions: the Faculty of Technical Sciences at the University of Novi Sad and the Faculty of Mechanical Engineering at the University of Belgrade. Since no statistically significant differences were observed between students from the two faculties across any of the analyzed variables, they were treated as a single sample of engineering students in subsequent analyses.

Of the total sample, 188 students (69.9%) were male and 81 students (30.1%) were female. Regarding their academic year and exposure to mathematics courses, 118 students (43.9%) were first-year students who had completed one mathematics course, while 151 students (56.1%) were third-year students who had successfully completed multiple mathematics courses.

The study also considered the type of secondary education as a potentially relevant variable. Among the participants, 181 students (67.3%) had completed grammar school, whereas 88 students (32.7%) had completed vocational secondary school.

Procedure

Data were collected using a structured questionnaire designed to examine three key dimensions of students' experience with learning mathematics (Fig. 1): (1) attitudes and self-assessment, (2) the use of information and communication technologies (ICT), and (3) learning strategies. The questionnaire was based on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). Students completed the questionnaire voluntarily after attending regular lectures in the classroom setting.

Attitudes and Self-Assessment in Learning Mathematics

The first subscale focused on students' attitudes toward mathematics and their self-perceptions as learners. It included items addressing the following aspects: motivation and emotional engagement, self-assessment of mathematical competence, perceived importance of mathematics, its usefulness in real-life and professional contexts, and preferred learning depth and style. This subscale demonstrated acceptable internal consistency, with a Cronbach's alpha coefficient of 0.77.

Use of ICT Resources

The second subscale examined how students utilize various ICT tools in the context of learning mathematics. This section included items related to the use of:

- digital learning materials (e.g., PDF textbooks, video lectures),
- specialized mathematical applications and tools (e.g., GeoGebra, MATLAB),
- visualization software for conceptual understanding,
- platforms for searching additional academic resources,
- communication tools for peer collaboration and task sharing (e.g., messaging apps, online forums, social media).

Learning Strategies and Habits

The third subscale explored students' general learning strategies, with particular emphasis on the sequence and depth of content engagement. Key topics included whether students prefer to study theoretical concepts before solving practical tasks or vice versa, and the relative importance they place on using textbooks compared to their personal lecture notes. This subscale also showed acceptable reliability, with a Cronbach's alpha of 0.62.

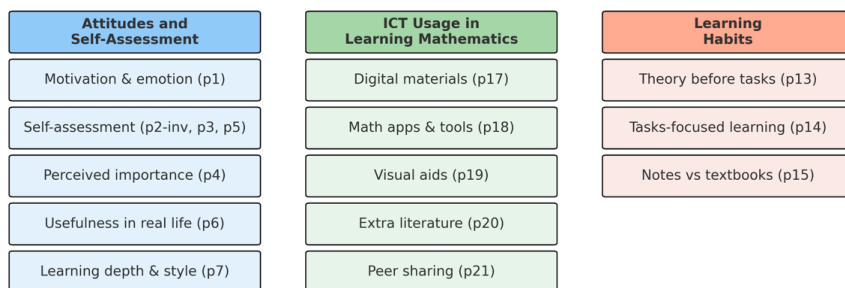


Figure 1. Schematic representation of the subscales utilized in the research instrument.

Data analysis

Descriptive statistics were calculated for all questionnaire items to summarize response patterns across the three subscales. Differences in students' attitudes, use of ICT resources, and learning strategies were examined in relation to gender, number of completed mathematics courses (first-year vs. third-year students), and type of secondary school completed (grammar school vs. vocational school). Given the ordinal nature of the data and the absence of normal distribution, the non-parametric Mann-Whitney U test was applied to assess statistically significant differences between groups. All data processing and statistical analyses were performed using Python (version 3.11).

RESULTS

Attitudes and Self-Assessment in Learning Mathematics

Descriptive statistics for the attitude scale are presented in Table 1. The highest mean score was recorded for *Perceived Importance* (p4, $M = 4.20$, $SD = 0.93$), indicating that students generally perceived mathematics as an important subject. This was closely followed by *Motivation & Emotion* (p1, $M = 3.91$) and *Learning Depth & Strategy* (p7, $M = 3.84$), suggesting a relatively strong engagement and strategic approach to learning mathematics.

In contrast, the lowest mean was observed for *Self-assessment* (p2, $M = 2.89$); however, this item was inversely coded, meaning that lower scores indicate higher self-assessment. The mode for this item was 2, further supporting the interpretation that many students positively evaluated their own mathematical abilities. Similarly, *Knowledge Evaluation* (p5, $M = 3.73$) and *Prior Knowledge* (p3, $M = 3.51$) showed moderately high scores, suggesting that students generally perceived themselves as reasonably familiar with and capable of evaluating mathematical content.

Table 1. Descriptive statistics for items measuring students' attitudes toward mathematics.

Question	Description	Mean	Std Dev	Mode
p1	Motivation & Emotion	3.91	1.1	5
p2	Self-assessment (inversely)	2.89	1.19	2
p3	Prior knowledge	3.51	1.13	4
p4	Perceived Importance	4.20	0.93	5
p5	Knowledge Evaluation	3.73	0.97	4
p6	Usefulness in Real Life	3.01	1.19	4
p7	Learning Depth & Strategy	3.84	1.13	5

To further explore students' attitudes toward mathematics, additional analyses were conducted to examine differences based on key background factors: gender, number of completed mathematics courses, type of secondary school previously completed, and year of study. Statistically significant differences were identified for several items, as shown in Table 2.

Table 2. Results of Mann–Whitney U tests for differences in attitude items by students' background characteristics.

Question	Factor	Group 1	Group 2	Mean 1	Mean 2	U-value	p-value
p3	Type of school	Grammar	Vocational	3.64	3.24	9550	0.006
p1	Course	More	One	4.04	3.75	10126	0.0433
p5	Course	More	One	3.85	3.58	10398	0.0139

Statistically significant differences were observed in several attitudinal items based on students' background characteristics. Students who had completed more than one mathematics course reported higher motivation and emotional engagement (p1, $M = 4.04$) compared to those who had completed only one course ($M = 3.75$; $p = 0.0433$). Similarly, they rated mathematical knowledge (p5) more positively ($M = 3.85$ vs. 3.58 ; $p = 0.0139$).

In addition, a significant difference was found in perceived prior knowledge (p3) based on the type of secondary school completed. Students from grammar schools reported higher levels of prior knowledge ($M = 3.64$) than those from vocational schools ($M = 3.24$; $p = 0.006$), suggesting a potential gap in foundational mathematical preparation between these groups.

Use of ICT Resources

In the second part of the study, students were asked to evaluate the extent to which they use various ICT resources in learning mathematics (Table 3). Among the listed resources, students most strongly agreed with the statement related to *peer sharing of tasks via social media* (p21, $M = 4.31$, $SD = 0.94$), indicating that this is the most commonly used ICT-related activity. *Digital materials* such as e-textbooks and lecture notes (p17) were also frequently used ($M = 3.88$), with the mode value of 5 suggesting high agreement across responses.

In contrast, the least utilized resources were *mathematics-specific applications or software* (p18, $M = 2.77$) and *visualization tools for mathematical content* (p19, $M = 2.74$), both with a mode of 2, indicating general disagreement or neutrality. Searching for additional literature (p20) received a moderate score ($M = 3.14$), suggesting occasional but not widespread use.

Table 3. Students' use of ICT resources in learning mathematics.

Question	Description	Mean	Std Dev	Mode
p17	Digital materials	3.88	1.07	5
p18	Math apps/software	2.77	1.28	2
p19	Visualization of math content	2.74	1.14	2
p20	Finding additional literature	3.14	1.26	2
p21	Peer sharing tasks via social media	4.31	0.94	5

To examine whether students' use of ICT resources in learning mathematics differs across background factors, Mann–Whitney U tests were conducted. Statistically significant differences were identified for two items, as shown in Table 4.

Female students reported significantly higher use of *peer sharing of tasks via social media* (p21) compared to male students ($M = 4.56$ vs. 4.21 ; $p = 0.0028$), indicating a greater tendency among female students to engage in collaborative learning through digital platforms.

In addition, a significant difference was observed in *searching for additional literature* (p20) based on the number of mathematics courses completed. Students who had completed only one course reported higher usage of this resource ($M = 3.41$) compared to those who had completed multiple courses ($M = 2.93$; $p = 0.0024$).

Table 4. Statistically significant differences in students' use of ICT resources based on gender and number of completed mathematics courses.

Question	Factor	Group 1	Group 2	Mean 1	Mean 2	U-value	p-value
p21	Gender	F	M	4.56	4.21	9188	0.0028
p20	Course	More	One	2.93	3.41	7033.5	0.0024

Learning Strategies and Habits

In the third part of the study, students were asked about their preferred learning strategies when studying mathematics, with a particular focus on whether they tend to engage with theoretical material before solving problems. Descriptive statistics for these items are presented in Table 5.

The results indicate that students predominantly learn through solving tasks rather than starting with theoretical content. The item “*Learning through tasks*” (p14) received a relatively high mean score ($M = 3.76$), suggesting that many students rely on a practice-oriented approach. Similarly, “*Using lecture notes over textbooks*” (p15) was rated highly ($M = 3.86$, mode = 5), indicating a preference for condensed or instructor-guided materials.

In contrast, the item “*Studying theory before attempting tasks*” (*p13*) received the lowest mean score ($M = 2.48$, mode = 2), showing that most students do not follow a theory-first strategy when learning mathematics. These results point to a more pragmatic and task-driven learning habit among the participants.

Table 5. Students’ learning strategies in mathematics.

Question	Description	Mean	Std Dev	Mode
p13	Theory before tasks	2.48	1.28	2
p14	Learning through tasks	3.76	1.21	4
p15	Notes over textbooks	3.86	1.17	5

Further analysis revealed statistically significant differences across subgroups. Regarding *p13*, students enrolled in 2021 reported a significantly higher preference for theory-first learning compared to those from the 2020 cohort ($p = 0.0002$). Similarly, students who completed grammar school gave higher ratings than those from vocational schools ($p = 0.0052$), suggesting that prior educational background may influence learning approach.

For *p15*, students from the 2020 cohort reported a stronger preference for lecture notes over textbooks compared to the 2021 cohort ($p = 0.0123$). In addition, students who attended more course rated this item significantly higher than those who attended one course ($M = 4.11$ vs. 3.53 ; $p = 0.0001$), indicating potential differences in instructional design or course culture that affect study habits.

DISCUSSION AND CONCLUSION

Attitudes and Self-Assessment in Learning Mathematics

The results of this study indicate that engineering students generally exhibit a positive attitude toward mathematics, highlighting both the importance of the subject and their own motivation to learn it. Students’ perception of the relevance of mathematics to their engineering studies and future careers appears to be a key factor shaping their engagement. As noted by previous research, students who understand the practical applications of mathematics within engineering contexts are more likely to appreciate and actively engage with mathematical content (Parsons, 2006; Zavala & Dominguez, 2016; Gold, 2015). Conversely, a lack of understanding of how mathematical concepts apply to real-world engineering problems can hinder student engagement (Panaoura et al., 2024).

Our findings suggest that engineering students not only demonstrate positive attitudes, but also hold a high level of confidence in their own mathematical knowledge. Many participants rated their abilities favorably and perceived themselves as competent in mathematics. This combination of interest, appreciation of relevance, and self-confidence represents an encouraging profile for future engineers. As highlighted in the literature, such positive attitudes and strong self-efficacy beliefs are associated with better academic outcomes, regardless of students’ prior qualifications (Parsons, 2006; Panaoura et al., 2024; Morán-Soto & Benson, 2018). Furthermore, self-efficacy has been shown to influence students’ willingness to engage with more demanding mathematical tasks and to seek support when encountering difficulties (Morán-Soto & Benson, 2018).

Although the overall attitudes were positive, further analysis revealed certain differences based on students’ educational backgrounds. Those who had completed grammar school reported significantly higher self-assessments of their mathematical knowledge compared to students from vocational secondary schools. In addition, students who had completed more mathematics courses at the university level not only perceived their knowledge more positively, but also reported higher motivation and a more favorable attitude toward the subject. These findings suggest that continued exposure to mathematics through university coursework may further enhance students’ appreciation and confidence, reinforcing the value of effective higher education instruction in fostering positive dispositions toward mathematics.

Use of ICT Resources

The results of this study show that engineering students most commonly use information and communication technologies (ICT) to access and utilize electronic materials for learning mathematics. This is partly due to the structure of university mathematics courses, where teaching content is often distributed in digital formats. The use of e-learning platforms and internet resources, including social networking mediums, has become an integral part of traditional instruction, supporting students in understanding mathematical concepts and solving problems more effectively (Mohd & Maat, 2013).

Another prominent function of ICT in this context is communication. Students frequently rely on ICT to collaborate and exchange materials with peers, often through informal channels that exclude teaching staff. These forms of communication, such as chat groups and messaging applications, serve as important spaces for peer-to-peer learning and the distribution of problem-solving strategies. The study also found that female students tend to use ICT slightly more often than their male peers, which may reflect differences in communication preferences or learning strategies.

Despite their regular engagement with digital technologies in everyday life, students reported relatively low levels of usage of mathematical tools and visualization software for learning purposes. This suggests an opportunity for improvement within formal instruction. While general access to digital content is widespread, many students are not familiar with or do not actively engage with mathematical applications, simulation environments, or platforms that enable the visualization of abstract concepts. Specific tools such as virtual laboratories, simulation software, and data analysis applications can help students connect mathematics to real-world engineering problems (Rasteiro et al., 2023). Visualization, in particular, is recognized as a powerful resource in supporting conceptual understanding (Cao et al., 2022), yet its pedagogical potential remains underused.

Given these findings, there is a clear need to guide students more intentionally in using specialized ICT resources for learning mathematics. Although they are generally technologically literate, students may not independently seek out tools that could enhance their learning. As previous research has suggested, even students who are immersed in technology in their daily lives do not always use it strategically for academic purposes, particularly in mathematics education (Saadati et al., 2014). Integrating relevant tools into regular instruction and actively encouraging their use may significantly contribute to more effective and engaged mathematical learning.

Learning Strategies and Habits

The findings of this study suggest that when learning mathematical content, engineering students tend to prioritize solving tasks over engaging with theoretical material. While this pragmatic approach may reflect students' desire for efficiency or practical relevance, it also highlights an opportunity for pedagogical improvement. Previous studies have emphasized the benefits of building a strong conceptual and theoretical foundation prior to tackling procedural tasks. For example, administering theoretical assessments before practical ones has been shown to enhance students' performance on applied tasks, as it helps consolidate their understanding of mathematical principles (Zeidmane and Atslega, 2014). A clear comprehension of fundamental laws supports more effective problem-solving and encourages deeper learning (Rooch et al., 2016).

This issue becomes particularly relevant in the context of the growing influence of artificial intelligence and digital automation. As computational tools increasingly take over routine and procedural tasks, students are expected to develop higher-order thinking and conceptual understanding that go beyond algorithmic execution. Emphasizing conceptual learning through well-structured instructional approaches and the integration of appropriate technologies can help students achieve a more meaningful grasp of mathematical ideas. Aligning theoretical instruction with practical applications, and presenting both in a way that emphasizes their interdependence, may enhance students' motivation and lead to more sustained engagement (Rooch et al., 2016).

Another important result concerns students' preferences for learning materials. Participants in this study expressed a strong inclination toward relying on their own lecture notes rather than using

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formal textbooks. This preference was more prominent among students in higher academic years, which suggests that experience in academic settings contributes to the development of personalized strategies that students perceive as more effective. These findings raise important questions regarding the adequacy and relevance of existing textbooks in higher mathematics education. More precisely, they point to the need for modernizing learning resources that serve as replacements for traditional textbooks (Anastasakis and Lerman, 2022).

Engineering students often supplement their learning using a wide array of tools such as online videos, virtual learning platforms, and peer discussions. These resources are often more accessible and more closely aligned with students' learning habits than conventional printed materials. In particular, the use of modern educational technologies, including interactive simulations, computer algebra systems, and dynamic visualization tools, enables students to explore mathematical concepts in more engaging and flexible ways. Such tools create learning environments that support experimentation, real-time feedback, and intuitive understanding, and may offer considerable pedagogical advantages compared to static content (Rasteiro et al., 2023). Enhancing the availability and integration of these resources into regular instruction could contribute to a more effective and personalized learning experience in mathematics education for future engineers.

In conclusion, the findings indicate that engineering students generally hold positive attitudes toward mathematics and confidence in their abilities, particularly those with stronger academic backgrounds. Digital technologies are widely used for accessing materials and collaborating with peers, while the use of advanced mathematical software and visualization tools remains limited. This points to the need for more purposeful integration of such tools and for a balanced approach that connects theory and practice to foster conceptual and critical thinking. Although the study is limited by its sample size and scope, the results suggest that future research should explore how artificial intelligence and adaptive technologies can further enhance mathematics learning in engineering education.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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ПЕРЦЕПЦИЈА РОДИТЕЉА МЛАЂЕ УЗРАСНЕ ГРУПЕ О УЛОЗИ ВАСПИТАЧА, ПРЕДШКОЛСКЕ УСТАНОВЕ И ЗНАЧАЈУ ФИЗИЧКОГ ВАСПИТАЊА

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САЖЕТАК

Циљ овог рада је да се сагледа улога васпитача и родитеља у подршци физичком васпитању деце предшколског узраста, као и фактори који утичу на квалитет њихове сарадње. Истраживање показује да је предшколска установа кључни носилац иницирања и подстицања партнерства са родитељима, што доприноси већем укључивању родитеља у васпитно-образовни процес и развијању здравих навика код деце.

Истраживање је спроведено на узорку родитеља деце млађих узрасних група у вртићима у Бањој Луци, различитих година, социјално-економског статуса и стручне спреме. Примењене су методе сервеја и теоријске анализе, а подаци су статистички обрађени једноставним фреквенцијама, кростабулацијом и χ^2 тестом.

Кључни налази указују да родитељи генерално имају позитиван став према раду васпитача, али истичу недостатак адекватних материјално-техничких услова у предшколским установама. Поред тога, утврђене су статистички значајне разлике у ставовима родитеља и васпитача у погледу материјално-техничких ресурса и реализације физичког васпитања, што указује на потребу за систематским унапређењем ових сегмената предшколског образовања.

УВОД

Сарадња између васпитача и родитеља представља један од кључних фактора квалитетног васпитно-образовног процеса у предшколској установи (Шврака, 2011; Бала и сар., 1996; Шврака, 2021). Њено унапређење захтева континуирано стручно усавршавање васпитача, како током иницијалног образовања, тако и кроз професионални развој током радног века. Посебно је важно обезбедити подршку васпитачима почетницима и онима који раде у условима ограничених материјално-техничких ресурса. „Квалитетно организовано, предшколско васпитање и образовање утиче на остваривање пуног потенцијала детета, а ефикасно доприноси остварењу постигнућа у даљем школовању и животу“ (Шврака, 2021, 7). Бројне студије указују на то да предшколска установа има водећу улогу у иницирању и развијању различитих облика сарадње са родитељима. Активно укључивање родитеља у рад вртића доприноси успостављању стабилног партнерства, преношењу позитивних навика у породични контекст и унапређењу физичког васпитања деце. „Родитељи играју кључну улогу у формирању навика везаних за физичку активност код деце предшколског, те да њихов лични пример и подршка директно утичу на ниво активности њихове деце“ (Ђорђевић, 2007, 23).

Укљученост родитеља не умањује професионалну аутономију васпитача, већ је допуњује и обогаћује, што резултира бољом подршком развоју детета. „Отвореност васпитног система се дефинише кроз превазилажење строгих институционалних оквира, активну партиципацију родитеља и локалне заједнице, као и флексибилно прилагођавање васпитно-образовног процеса актуелним потребама деце кроз синергију са ширим социјалним окружењем“ (Маринковић, 1995, 37). Породица, као примарни агенс социјализације, има кључну улогу у формирању здравих навика и подстицању физичке активности од најранијег узраста. Примена редовних, развојно прилагођених активности

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доприноси изградњи трајних навика и интересовања, при чему је игра најприроднији медиј за развој мотивације детета. „Физичка активност, је једно од основних здравствених понашања, која има изузетно повољан и вишеструки утицај на све развојне аспекте предшколске деце.“ (Бала и сар., 2006, 24)

Васпитач има значајну улогу у овом процесу: његов професионални став, лични ангажман и квалитет комуникације са родитељима снажно утичу на обим и квалитет сарадње. Неповерење или пасивност било које стране може нарушити партнерство, док је међусобна подршка предуслов за стварање подстицајног окружења за свеукупни развој детета, укључујући и његов физички развој.

МЕТОДОЛОГИЈА

Узорак

Узорак истраживања чинили су родитељи оба пола чија деца похађају млађе узрасне групе вртића у Бањој Луци. Испитаници се разликују према годинама старости, социјално-економском статусу и степену стручне спреме, што омогућава разматрање ставова различитих социјалних категорија родитеља. Узорак је намерно формиран, у складу са циљем истраживања и доступношћу испитаника.

Инструменти

За прикупљање података коришћен је анкетни упитник, конструисан за потребе овог истраживања. Упитник је садржао питања затвореног типа, груписана у сегменте који се односе на:

- перцепцију улоге васпитача,
- оцену функционисања предшколске установе,
- ставове о значају и квалитету физичког васпитања,
- основне социодемографске карактеристике родитеља.

Пре главне примене инструмента извршена је провера јасноће питања и контрола доследности, након чега је упитник финално прилагођен за примену.

Поступак истраживања

Подаци су прикупљени у оквиру предшколских установа, уз претходну сагласност родитеља и поштовање етичких начела научног истраживања. Након прикупљања извршена је контрола и сређивање података, провера валидности одговора и трансформација варијабли у складу са постављеним циљевима истраживања.

Методе истраживања

У истраживању је примењен **сервеј метод** као основна емпиријска метода, као и **метода теоријске анализе**, која је коришћена за постављање теоријског оквира и интерпретацију добијених резултата.

Методе статистичке обраде података

За анализу дистрибуције одговора коришћене су:

- метода једноставних фреквенција,
- метода кростабулације (за утврђивање односа категоријских варијабли),
- Хи-квадрат тест (χ^2) за тестирање статистички значајних разлика између остварених и теоријских фреквенција.

Статистичка значајност процењивана је на алфа нивоу од 0,05, уз прихватање 5% грешке у процени.

Циљ истраживања

Основни циљ овог истраживања јесте систематско сагледавање перцепција родитеља деце млађе узрасне групе о uloзи васпитача, функцији и значају предшколске установе и

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месту физичког васпитања у раном детињству. Циљ је и да се утврди постоје ли статистички значајне разлике у ставовима родитеља у односу на наведене области. Додатни циљ представља конструисање и валидирање методолошки адекватног инструмента за прикупљање података, који омогућава свеобухватну и поуздану анализу фактора који обликују ставове родитеља о предшколском васпитању и физичком развоју деце.

Хипотезе истраживања

На основу предмета и циља истраживања формулисана је основна (општа) хипотеза, као и припадајуће подхипотезе.

Општа хипотеза

Н₀: Претпоставља се да родитељи перципирају физичко васпитање као једну од кључних и најзначајнијих области васпитно-образовног процеса у предшколској установи.

Подхипотезе

Н₁: Квалитет рада васпитача у области физичког васпитања статистички значајно зависи од степена опремљености предшколске установе справама и реквизитима намењеним за реализацију физичких активности.

Н₂: Социјално-статусне карактеристике родитеља представљају статистички значајне детерминанте њихових ставова о настави физичког васпитања.

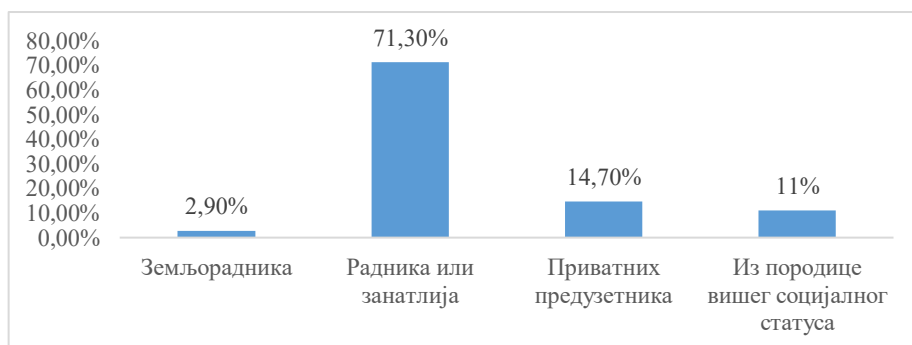
Н₃: Постоје статистички значајне разлике између родитеља и васпитача у ставовима о настави физичког васпитања, као и у процени материјално-техничких ресурса предшколске установе.

РЕЗУЛТАТИ ИСТРАЖИВАЊА

У табели 1 и графикону 1 приказана је расподела испитаника према социјалном пореклу.

Табела 1. Према социјалном пореклу потичем из породице?

Одговори	Статистика	Учесталост
Земљорадника	Број %	4 2,9%
Радника или занатлија	Број %	97 71,3%
Приватних предузетника	Број %	20 14,7%
Из породице вишег социјалног статуса	Број %	15 11,0%
Укупно	Број %	136 100,0%



Графикон 1. Дистрибуција одговора родитеља и васпитача о социјалном пореклу ($\chi^2 = 1,687$, $p = 0,64$).

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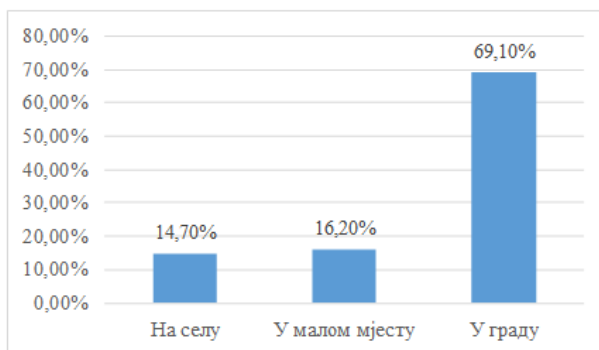
Када се упореди дистрибуција одговора родитеља и васпитача (Графикон 1) види се да је разлика у дистрибуцији фреквенција одговора минимална. То је потврдило и тестирање разлика у дистрибуцији путем хи-квадрат теста који је показао да нема статистички значајне разлике у погледу социјалног порекла испитаника ове две групе. Нешто већи проценат васпитача потиче из породица вишег социјалног статуса, док већи проценат родитеља потиче из породица радника и занатлија.

Анализа дистрибуције питања везаног за демографско порекло испитаника (Табела 2) показала је да већина испитаника потиче из градске средине (69,1%).

Анализа разлика у дистрибуцији демографског порекла испитаника родитеља и васпитача (Графикон 2), показала је да разлике нису статистички значајне. Највећи број испитаника у обе групе одрасло је у градској средини. Интересантан је податак да је дупло већи проценат васпитача (22%) одрасло у сеоској средини у односу на родитеље (11,6%).

Табела 2. Детињство и рану младост провео/ла сам?

Одговори	Статистик	Учесталост
На селу	Број %	20 14,7%
У малом мјесту	Број %	22 16,2%
У граду	Број %	94 69,1%
Укупно	Број %	136 100,0%

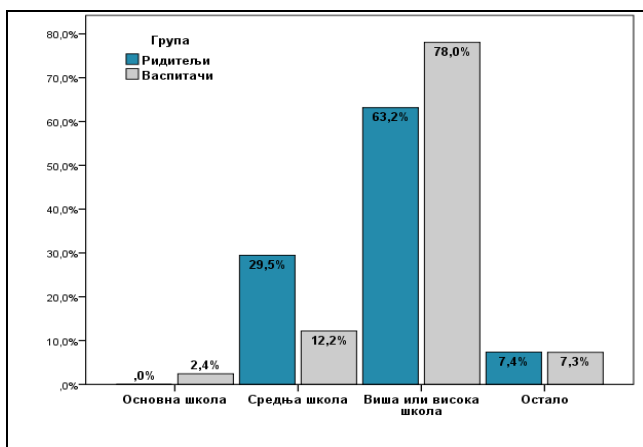


Графикон 2. Дистрибуција одговора родитеља и васпитача на питање: Детињство и рану младост провео/ла сам ($X^2 = 2,761$, $p = 0,251$).

У односу на степен образовања (Табела 3) већина испитаника се изјаснила да има завршену вишу или високу школу. Само један испитаник је имао завршену основну школу а њих 10 је завршило неку врсту мастер или докторских студија.

Табела 3. Степен завршене школе?

Одговори	Статистика	Учесталост
Основна школа	Број %	1 0,7%
Средња школа	Број %	33 24,3%
Виша или висока школа	Број %	92 67,6%
Остало	Број %	10 7,4%
Укупно	Број %	136 100,0%



Графикон 3. Дистрибуција одговора родитеља и васпитача на питање: Степен завршене школе ($\chi^2 = 6,780$, $p = 0,079$).

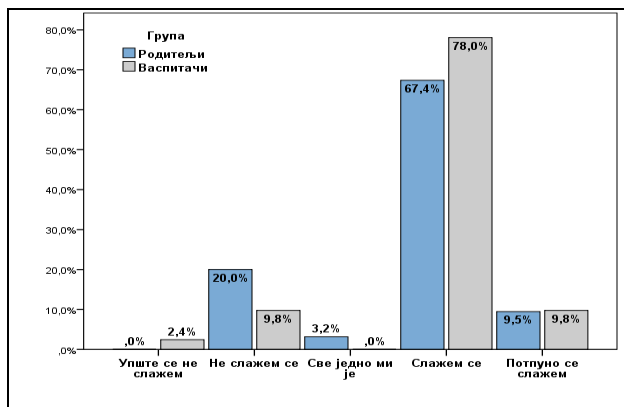
Када се анализира структура дистрибуције одговора васпитача и родитеља (Графикон 3), уочава се да је значајно већи проценат васпитача са вишом и високом стручном спремом у односу на родитеље. То се могло и очекивати обзиром на професију васпитача где је потребна висока стручна спрема за обављање тих послова. Тестирање уочених разлика у дистрибуцији одговора између анализираних група ипак није показало статистички значајан ниво.

Изнесена анализа социјалних, демографских и образовних карактеристика узорка испитаника обухваћених истраживањем, показала је да је узорак доста изједначен у односу на те карактеристике. То наводи на закључак да поменуте карактеристике нису значајно утицале на природу и карактер одговора испитаника анализираних група родитеља и васпитача.

Табела 4. Искусан васпитач може и без припреме да успешно изведе усмерену активност?

Одговори	Статистик	Учесталост
Уопште се не слажем	Број %	1 0,7%
Не слажем се	Број %	23 16,9%
Све једно ми је	Број %	3 2,2%
Слажем се	Број %	96 70,6%
Потпуно се слажем	Број %	13 9,6%

Дистрибуција одговор на ово питање по анализираним групама (Графикон 4), показала је да се васпитачи у већем проценту слажу са тврдњом (87,8%), док је 20% родитеља изразило не слагање са таквом тврдњом. Ипак, уочене разлике у дистрибуцији нису статистички значајне.



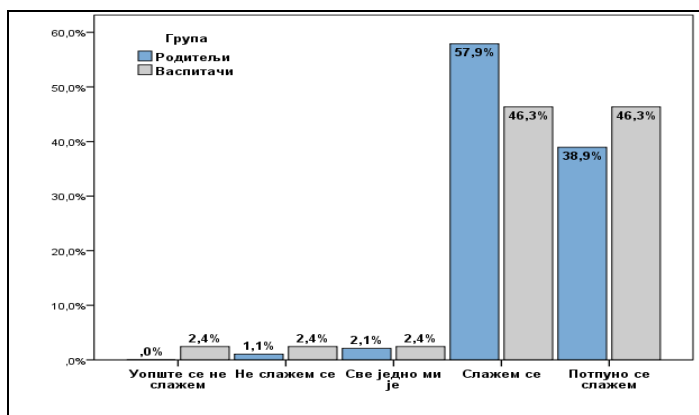
Графикон 4. Дистрибуција одговора родитеља и васпитача на питање: Искусан васпитач може и без припреме да успешно изведе усмерену активност ? ($X^2 = 5,854$, $p = 0,210$).

Васпитач се треба свакодневно усавршавати у својој струци.

Изразито висок проценат испитаника се сложио или потпуно сложио са овом тврдњом (Табела 5). Посебно треба истаћи да се 41,2% испитаника у потпуности сложило са том тврдњом. То јасно указује на то да испитаници сматрају да је стално усавршавање васпитача веома важан фактор у њиховом успешном раду са децом.

Табела 5. Васпитач се треба свакодневно усавршавати у својој струци.

Одговори	Статистика	Учесталост
Уопште се не слажем	Број %	1 0,7%
Не слажем се	Број %	2 1,5%
Све једно ми је	Број %	3 2,2%
Слажем се	Број %	74 54,4%
Потпуно се слажем	Број %	56 41,2%



Графикон 5. Дистрибуција одговора родитеља и васпитача на тврдњу: Васпитач се треба свакодневно усавршавати у својој струци ($X^2 = 3,789$, $p = 0,435$).

Švraka, N. i Švraka, V. (2025). Percepcija roditelja mlađe uzrasne grupe o ulozi vaspitača, predškolske ustanove i značaju fizičkog vaspitanja. *STED Conference 14(2)*, 419-432.

Испитаници обе анализиране групе имају веома висок проценат слагања са тврдњом да је потребан стални рад на усавршавању код васпитача (Графикон 5). Занемарљив проценат испитаника је неодлучан или се не слаже са том тврдњом. Као и код претходних питања, ни код овога није присутна статистички значајна разлика у дистрибуцији одговора васпитача и родитеља.

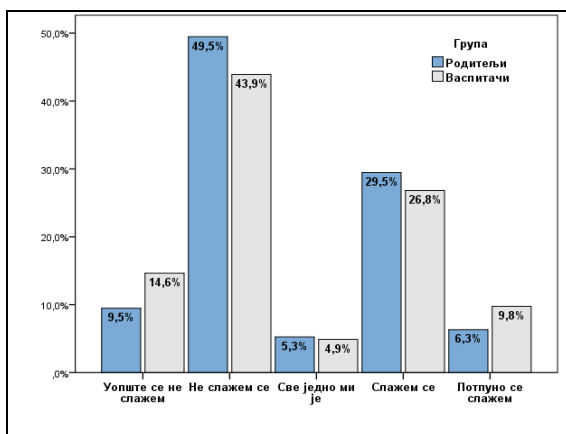
Социјални статус родитеља утиче на њихов однос према васпитачу.

Већина испитаника је исказало неслагање са ставом да социјални статус родитеља утиче на њихов став према васпитачима (Табела 6).

Међутим, уочљиво је и да се 36,1% испитаника сложило са том тврдњом. Разлике између анализираних група нису статистички значајне (Графикон 6).

Табела 6. Социјални статус родитеља утиче на њихов однос према васпитачу

Одговори	Статистик	Учесталост
Уопште се не слажем	Број %	15 11,0%
Не слажем се	Број %	65 47,8%
Све једно ми је	Број %	7 5,1%
Слажем се	Број %	39 28,7%
Потпуно се слажем	Број %	10 7,4%



Графикон 6. Дистрибуција одговора родитеља и васпитача на тврдњу: Социјални статус родитеља утиче на њихов однос према васпитачу ($X^2 = 1,417$; $p = 0,841$)

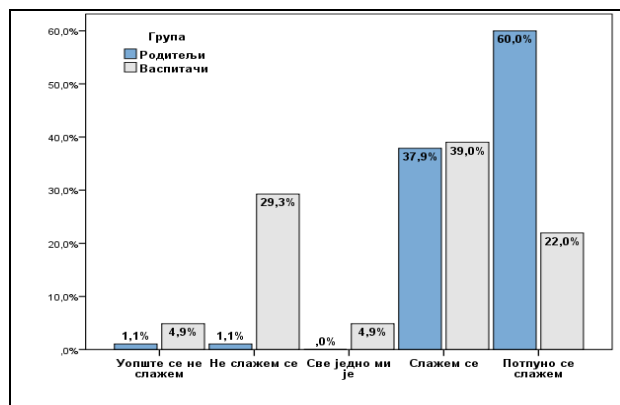
Васпитач треба да укаже родитељу на евентуалне физичке неправилности код детета

Испитаници се у високом проценту слажу са тиме да васпитачи треба да указују родитељима на уочене неправилности у физичком развоју деце (Табела 7).

Међутим, када се погледа дистрибуција одговора по групама (Графикон 7), запажа се да је видно већи проценат родитеља који се слажу са том тврдњом, готово сви (97,9%), док су васпитачи резервисанији у вези ове тврдње и трећина њих сматра да то није неопходно. Уочене разлике између родитеља и васпитача су статистички значајне.

Табела 7. Вaspитач треба да укаже родитељу на евентуалне физичке неправилности код детета

Одговори	Статистик	Учесталост
Уопште се не слажем	Број	3
	%	2,2%
Не слажем се	Број	13
	%	9,6%
Све једно ми је	Број	2
	%	1,5%
Слажем се	Број	52
	%	38,2%
Потпуно се слажем	Број	66
	%	48,5%



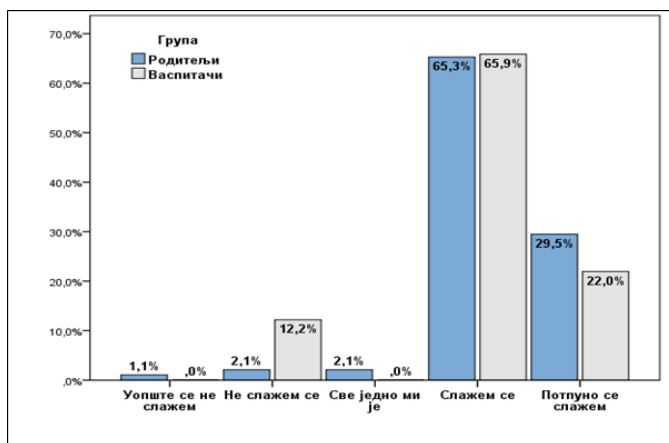
Графикон 7. Дистрибуција одговора родитеља и вaspитача на тврдњу: Вaspитач треба да укаже родитељу на евентуалне физичке неправилности код детета ($X^2 = 38,940$; $p = 0,001$)

Предшколска установа треба да обезбеди сва потребна средства и реквизите за успешно обављање физичке активности.

Преко 90% испитаника сматра да предшколска установа треба да обезбеди сва потребна средства и реквизите за реализацију наставе физичког вaspитања (Табела 8). Нема статистички значајне разлике у дистрибуцији одговора родитеља и вaspитача (Графикон 8). Приметан је извесан проценат вaspитача који се не слажу са датом тврдњом (12,2%).

Табела 8. Предшколска установа треба да обезбеди сва потребна средства и реквизите за успешно обављање физичке активности.

Одговори	Статистик	Учесталост
Уопште се не слажем	Број	1
	%	0,7%
Не слажем се	Број	7
	%	5,1%
Све једно ми је	Број	2
	%	1,5%
Слажем се	Број	89
	%	65,4%
Потпуно се слажем	Број	37
	%	27,2%



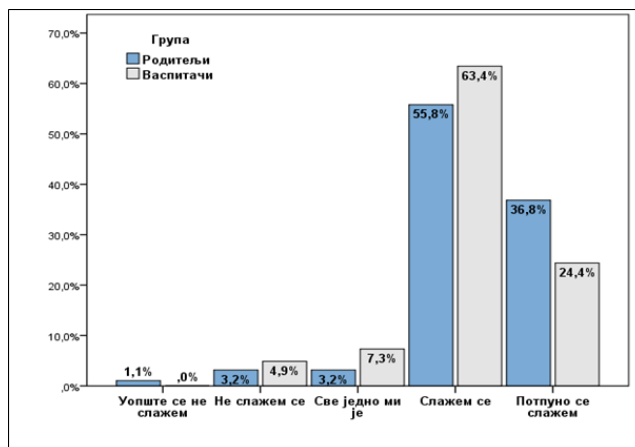
Графикон 8. Дистрибуција одговора родитеља и васпитача на тврдњу: Предшколска установа треба да обезбеди сва потребна средства и реквизите за успешно обављање физичке активности ($X^2 = 7,557$; $p = 0,109$)

У предшколској установи треба организовати редовне прегледе физијатра

Анкетирани испитаници су исказале веома висок проценат слагања са тврдњом да је у предшколској установи потребно организовати редовне прегледе физијатра (Табела 9). Дистрибуција одговора родитеља и васпитача је готово подударна и није утврђена статистички значајна разлика између њих (Графикон 9).

Табела 9. У предшколској установи треба да се организују редовни прегледи физијатра

Одговори	Статистик	Учесталост
Уопште се не слажем	Број %	1 0,7%
Не слажем се	Број %	5 3,7%
Све једно ми је	Број %	6 4,4%
Слажем се	Број %	79 58,1%
Потпуно се слажем	Број %	45 33,1%



Графикон 9. Дистрибуција одговора родитеља и васпитача на тврдњу: У предшколској установи треба да се организују редовни прегледи физијатра ($X^2 = 3,414$; $p = 0,491$).

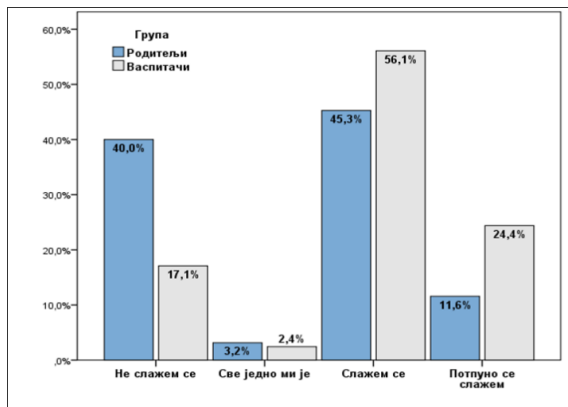
Švraka, N. i Švraka, V. (2025). Percepcija roditelja mlađe uzrasne grupe o ulozi vaspitača, predškolske ustanove i značaju fizičkog vaspitanja. *STED Conference 14(2)*, 419-432.

Физичко васпитање је најважнија област развоја деце у предшколској установи

Дистрибуција одговора на ово питање је изразито поларизована (Табела 10). Готово подједнак проценат испитаника се не слаже и слаже са овом тврдњом. Утврђена је статистички значајна разлика између родитеља и васпитача (Графикон 10). При томе, васпитачи имају изразито позитиван став према томе, док су родитељи доста резервисани и подељени у ставу.

Табела 10. Физичко васпитање је најважнија област развоја деце у предшколској установи

Одговори	Статистик	Учесталост
Не слажем се	Број %	45 33,1%
Све једно ми је	Број %	4 2,9%
Слажем се	Број %	66 48,5%
Потпуно се слажем	Број %	21 15,4%



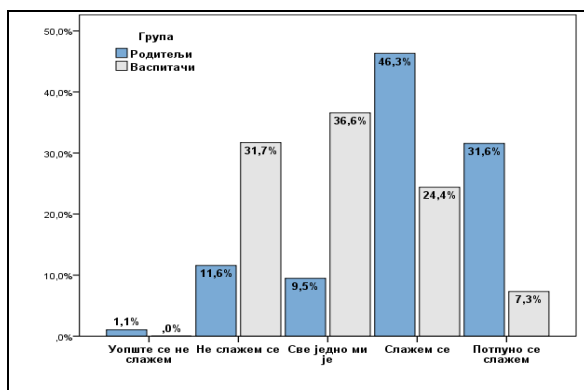
Графикон 10. Дистрибуција одговора родитеља и васпитача на тврдњу: Физичко васпитање је најважнија област развоја деце у предшколској установи ($X^2 = 8,337$; $p = 0,040$).

У свакој предшколској установи треба да постоји стручни сарадник за физичко васпитање

Највећи проценат испитаника се слаже са овом тврдњом (Табела 11) али је приметан и доста висок проценат неодлучних одговора (17,6%). Код овог питања је утврђена статистички значајна разлика у дистрибуцији одговора родитеља и васпитача. Док су родитељи већином позитивног става према овој тврдњи, васпитачи имају доста негативан и изненађујуће неодлучан став према датој тврдњи.

Табела 11. У свакој предшколској установи треба да постоји стручни сарадник за физичко васпитање

Одговори	Статистик	Учесталост
Уопште се не слажем	Број %	1 0,7%
Не слажем се	Број %	24 17,6%
Све једно ми је	Број %	24 17,6%
Слажем се	Број %	54 39,7%
Потпуно се слажем	Број %	33 24,3%



Графикон 11. Дистрибуција одговора родитеља и васпитача на тврдњу: У свакој предшколској установи треба да постоји стручни сарадник за физичко васпитање ($X^2 = 29,351$; $p = 0,000$).

Анализа збирних резултата анкете родитеља

Ради свеобухватније анализе резултата анкете она је реализована примјеном скале Ликертовог типа са пет скалних вриједности, односно интензитета слагања са датим тврдњама. То је имало за циљ формирање 4 композитне варијабле: *Квалитет рада васпитача* (6 ајтема), *Материјални услови рада* (6 ајтема), *Социјално статусна обиљежја родитеља* (6 ајтема) и *Учесталост физичког васпитања* (8 ајтема).

На тај начин је омогућена квалитетнија анализа дистрибуције ставовима родитеља према ове четири одреднице рада предшколских установа, као и поређења са ставовима васпитача.

Дистрибуција збирних скорова четири композитне варијабле анализирана је у односу на средњу референтну вриједност која за варијабле *Квалитет рада васпитача*, *Материјални услови рада* и *Социјално статусна обележја родитеља* износи 18 (6 x 3) а за варијаблу *Учесталост физичког васпитања* 24 (8 x 3).

Дистрибуција фреквенција збирних скорова родитеља за варијаблу *Квалитет рада васпитача* статистички значајно одступа од теоретски очекиваних фреквенција ($X^2=63,6$; $p=0,001$) и показује уочљиву асиметрију ка зони виших вредности. То указује на то да је општи став родитеља према потреби квалитетног рада васпитача позитиван, што је било присутно и код већине питања која су формирала ову композитну варијаблу. Дистрибуција збирних скорова за варијаблу *Квалитет рада васпитача*

Када се погледа дистрибуција скорова у односу на референтну линију очекиваног средишњег скорa (18), види се да је степен слагања родитеља са тврдњама везаним за квалитет рада васпитача изразито афирмативан. Родитељи очекују да су васпитачи максимално едуковани, да се стално усавршавају и имају савремен стил рада са децом.

Дистрибуција фреквенција збирних скорова родитеља за варијаблу *Материјални услови рада* такође статистички значајно одступа од теоретски очекиваних фреквенција ($X^2=88,1$; $p=0,001$), асиметрична и такође указује на изразито позитиван став родитеља о питањима везаним за материјалне услове рада предшколске установе. Веома мали број збирних скорова је испод вредности референтне линије (18). То је и разумљиво обзиром да родитељи очекују од друштва, односно предшколске установе, да обезбеди максималне услове за боравак деце у предшколској установи и што квалитетнији рад са њима током боравка.

Дистрибуција фреквенција збирних скорова родитеља за варијаблу *Социјално статусна обележја испитаника* (такође статистички значајно одступа од теоретски очекиваних фреквенција ($X^2=60,4$; $p=0,001$), симетрична је али доста разуђена (распон од 8-30). Може се уочити присуство 2 модалне вриједности, једне у зони нижих вредности и једне у зони просечних вредности.

У односу на референтну линију очекиване средње вредности збирних скорова, већина резултата је мања од ње, што указује на то да су родитељи имали већи степен неслагања са

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тврдњама изнетим у питањима везаним за њихова социјално статусна обиљежја. Очигледно да су родитељи у већини случајева мишљења да њихова социјално статусна обележја нису одредница њиховог односа према васпитачима и предшколској установи уопште.

Дистрибуција фреквенција збирних скорова родитеља за варијаблу *Учесталост (Важност) физичког васпитања* такође статистички значајно одступа од теоретски очекиваних фреквенција ($X^2=57,5$; $p=0,001$), симетрична је али уочљиво негативно оријентисана односу на референтну вриједност збирног скорa. То јасно упућује на закључак да већина родитеља сматра да је број и обим рада на физичком васпитању у предшколској установи недовољан, а да је физичко васпитање важна чиниоц рада у предшколској установи, а посебно игра као њен основни појавни облик.

Анализа разлика ставова родитеља и васпитача

Обзиром да су добијени подаци анкете на параметријске природе, ординарног типа, урађена је провера нормалности њихове дистрибуције и анализа дескриптивних карактеристика формираних композитних варијабли. Анализа је показала да дистрибуција резултата у све четири варијабле статистички значајно одступа од нормалне.

Вредности Shapiro-Wilk теста су биле изнад граничних вредности уз алфа ниво процене од $p \leq 0,05$. Дистрибуција резултата у анализираним варијаблама је доста хомогена (коэффициенти варијабилности су у распону од 10-22%), посебно у прве две варијабле, што указује на малу варијабилност резултата узорка испитаника у целисти.

Табела 12. Дистрибуција композитних варијабли

Варијабле	АС	СД	КВ (%)	Мин.	Макс.	П
Квалитет рада васпитача	22,96	2,43	10,6	16	30	0,005
Материјални услови рада	22,23	2,89	13,0	13	30	0,049
Социјално статусна обиљежја родитеља	16,81	3,62	21,9	8	30	0,035
Учесталост физичког васпитања	17,30	3,69	21,3	10	25	0,001

АС – аритметичка средина; СД – стандардна девијација; КВ – коэффициент варијабилности; Мин. – минимална вриједност; Макс. – Максимална вредност; П – значајност Shapiro-Wilk теста нормалности дистрибуције.

Изнета анализа дескриптивних карактеристика формираних композитних варијабли на целом узорку испитаника, указала је на потребу да се тестирање разлика између група родитеља и васпитача уради не парметријском методом уз примјену Mann-Whitney теста за два независна узорка. Овај тест је адекватна замјена за т тест независних узорака и није осетљив на одсуство нормалне дистрибуције и присутан дисбаланс величине група испитаника, што је у овом истраживању било присутно.

На основу урађене анализе може се констатовати да су разлике између родитеља и васпитача присутне у 2 од 4 анализиране варијабле. Статистички значајне разлике су утврђене у варијаблама *Материјални услови рада* и *Учесталост физичког васпитања*.

Табела 13. Резултати анализе разлика резултата родитеља (N=95) и васпитача (N=41) за формиране композитне варијабле

Варијабле	Група	Средњи ранг	Значајност теста
Квалитет рада васпитача	Родитељи	69,01	0,816
	Васпитачи	67,32	
Материјални услови рада	Родитељи	74,84	0,004
	Васпитачи	53,82	
Социјално статусна обиљежја родитеља	Родитељи	68,30	0,928
	Васпитачи	68,96	
Учесталост физичког васпитања	Родитељи	88,86	0,000
	Васпитачи	21,32	

На основу просечних вредности рангова види се да су родитељи у оба случаја имали већи просечни ранг од васпитача. То значи да су родитељи имали генерално већи степен слагања са тврдњама да су предшколске установе у обавези да обезбеде боље материјалне услове за рад, организују активности у природи и редовне прегледе физијатра. Васпитачи су били суздржанији у процјени значаја материјалних услова рада које треба да обезбеди сама предшколска установа.

Исто тако, родитељи су имали израженији општи степен слагања са тврдњама које истичу значај физичког васпитања у раду са предшколском децом, потребом побољшања стручног рада са децом у настави физичког васпитања као и неслагање са трајањем и учесталости тих физичких активности. Васпитачи су у исказали мањи степен слагања са тврдњама које су истицале важност физичког васпитања у раду са децом.

Приказана анализа потврдила је хипотезу о постојању разлика у ставовима родитеља и васпитача у односу на наставу физичког васпитања и материјално-техничког ресурса.

ЗАКЉУЧАК

Резултати овог истраживања потврђују основну хипотезу да родитељи деце млађе узрасне групе перципирају физичко васпитање као једну од кључних и најзначајнијих области васпитно-образовног процеса у предшколским установама. Ово указује на висок степен свести родитеља о значају физичког развоја у раном детињству и потребу да предшколске установе пружају континуирану подршку у овој области.

Подхипотеза Н₁, која је постављена у вези са опремљеношћу вртића, показала је да квалитет рада васпитача у великој мери зависи од материјално-техничких ресурса. Дефицитарност справа, реквизита и простора директно утиче на могућност реализације разноврсних физичких активности, што указује на потребу за стратешким улагањима у опрему и инфраструктуру предшколских установа како би се обезбедио квалитетан васпитно-образовни процес.

Подхипотеза Н₂, која се односи на утицај социјално-економских и образовних карактеристика родитеља на њихове ставове о физичком васпитању, показала је да постоје статистички значајне разлике у перцепцији важности и квалитета физичког васпитања. Ово резултира потребом за прилагођавањем облика сарадње и комуникације са родитељима различитих социјално-економских профила, како би се обезбедила равноправна и ефикасна подршка сваком детету у процесу развоја физичких и здравствених навика.

Подхипотеза Н₃ указује на постојање значајних разлика између родитеља и васпитача у перцепцији квалитета наставе физичког васпитања и материјално-техничких услова. Ови резултати наглашавају важност континуиране комуникације, размене информација и партнерског приступа у раду вртића, како би се уједначиле перцепције и очекивања, а самим тим и побољшала ефикасност васпитно-образовног процеса.

Укупно, налази истраживања истичу више нивоа интервенције који су потребни за унапређење физичког васпитања у предшколским установама:

- Материјални аспект: побољшање опреме, реквизита и простора за физичке активности;
- Професионални аспект: континуирана обука васпитача и развој њихових компетенција у области физичког васпитања;
- Сарадња са родитељима: развој партнерског односа који укључује активну подршку родитеља и усаглашена очекивања у вези са физичким активностима деце.

Ови резултати имају значајне теоријске и практичне импликације: теоријски, истраживање потврђује важност породице као примарног агенса социјализације и развоја здравих навика; практично, пружа смернице за унапређење предшколског васпитања, материјалних ресурса и партнерске сарадње са родитељима, што директно доприноси квалитетнијем развоју деце и формирању трајних здравих навика од најранијег узраста.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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TEACHERS, PRESCHOOL INSTITUTIONS, AND THE IMPORTANCE OF PHYSICAL EDUCATION PARENTS' PERCEPTION OF THE ROLR OF PRESCHOOL

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ABSTRACT

The aim of this study is to examine the role of educators and parents in supporting physical education for preschool-aged children, as well as the factors influencing the quality of their cooperation. The research indicates that the preschool institution plays a key role in initiating and promoting partnerships with parents, which contributes to greater parental involvement in the educational process and the development of healthy habits in children.

The study was conducted on a sample of parents of children in younger age groups attending kindergartens in Banja Luka, differing in age, socio-economic status, and educational background. The research employed survey and theoretical analysis methods, and the data were statistically processed using simple frequencies, cross-tabulation, and the χ^2 test.

The main findings show that parents generally have a positive attitude toward the work of educators but highlight the lack of adequate material and technical resources in preschool institutions. Additionally, statistically significant differences were identified between parents' and educators' perceptions regarding material-technical resources and the implementation of physical education, indicating the need for systematic improvements in these aspects of preschool education.

Keywords: perception, preschool teachers, preschool institutions, physical education

SPORTSKE AKTIVNOSTI KAO FAKTOR RAZVOJA MOTORIČKIH SPOSOBNOSTI PREDŠKOLSKE DJECE

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SAŽETAK

Predškolske ustanove imaju ključnu ulogu u stvaranju temelja za cjelokupan razvoj djeteta, uključujući fizički, emocionalni, kognitivni i socijalni aspekt. Kroz raznovrsne odgojno-obrazovne programe, posebna pažnja posvećuje se tjelesnim aktivnostima koje podržavaju razvoj motoričkih sposobnosti i usvajanje zdravih životnih navika. Planirane sportske aktivnosti ne samo da doprinose boljoj fizičkoj kondiciji, već i potiču socijalizaciju, razvoj discipline i stvaranje pozitivne slike o sebi. Cilj ovog istraživanja bio je analizirati učestalost, vrstu i intenzitet sportskih aktivnosti predškolske djece tijekom boravka u vrtiću, s posebnim naglaskom na njihove motoričke sposobnosti. Istraživanje je provedeno u Predškolskoj ustanovi u Mostaru, gdje su anketirani odgojitelji predškolske odgojne ustanove. Koristeći strukturirani anketni upitnik, prikupljeni su podaci o organizaciji i provedbi sportskih aktivnosti te njihovom utjecaju na razvoj djece u dobi od 3 do 5 godina.

Ključne riječi: razvoj, motoričke sposobnosti, sportske aktivnosti, predškolska djeca.

UVOD

Zdravlje je ključni aspekt života i usko je povezano s tjelesnom aktivnošću. Osim obitelji, odgojitelji imaju značajnu ulogu u poticanju djece na bavljenje sportskim aktivnostima. Svako dijete posjeduje svoj genetski potencijal koji se mora razvijati, a ako se to ne dogodi u predškolskoj dobi, šanse za daljnji razvoj se smanjuju. Osnovne motoričke vještine ključne su za kvalitetan život, a okruženje u kojem dijete odrasta mora biti stimulirajuće i raznoliko kako bi se omogućio pravilan razvoj. Razvoj motoričkih sposobnosti tijekom predškolske dobi omogućuje djeci temelj za složenije fizičke aktivnosti i doprinosi njihovom zdravlju. Osim fizičkog zdravlja, sportske aktivnosti utječu na emocionalni razvoj, socijalne vještine i suradnju. Razvoj motoričkih sposobnosti uključuje ravnotežu, koordinaciju, snagu, brzinu i izdržljivost, a ove vještine igraju važnu ulogu u fizičkom zdravlju djeteta i njegovoj sposobnosti suočavanja s izazovima. Redovita tjelesna aktivnost doprinosi zdravlju srca, kostiju i mišića te smanjuje rizik od bolesti poput pretilosti, dijabetesa i kardiovaskularnih bolesti. Djeca koja redovito sudjeluju u tjelesnim aktivnostima imaju bolji imunološki sustav, veću koncentraciju i više energije. Programi fizičkog odgoja koji su prilagođeni predškolskoj djeci mogu im pomoći u razvoju zdravih životnih navika, discipline i pozitivnog stava prema tjelesnoj aktivnosti. Djeca koja se bave tjelesnim aktivnostima od malih nogu obično ostaju aktivna i u odrasloj dobi, čime smanjuju rizik od razvoja različitih bolesti. Razvoj motoričkih sposobnosti je povezan s biokemijskim i morfološkim promjenama u tijelu i obuhvaća različite vještine poput snage, koordinacije, brzine, fleksibilnosti, preciznosti, ravnoteže i izdržljivosti.

Razvoj motoričkih sposobnosti u predškolskoj dobi ključno je za cjelokupni rast i razvoj djeteta. Osnovne motoričke vještine koje djeca usvoje u ovom razdoblju temelje su za daljnje složenije fizičke aktivnosti i zdravlje. Tjelesna aktivnost ne samo da razvija fizičke kompetencije, nego doprinosi i emocionalnom, kognitivnom i socijalnom razvoju djeteta. S obzirom na važnost ranog razvoja motoričkih sposobnosti, odgojno-obrazovne ustanove imaju odgovornost pružiti odgovarajuće programe tjelesnih aktivnosti koji su prilagođeni potrebama djece, a odgojitelji mogu igrati ključnu ulogu u razvoju tih sposobnosti i općem psihofizičkom zdravlju djece.

METODE RADA

Populacijau ovog istraživanja čine odgajatelji predškolske djece uzrasta od tri do šest godina. Uzorak je specifična grupa od 50 odgajatelja iz predškolske ustanove u Mostaru,. Ovaj uzorak može biti reprezentativan za specifične karakteristike ove ustanove, ali je važno napomenuti da se rezultati možda neće u potpunosti generalizirati na širu populaciju odgajatelja u drugim predškolskim ustanovama. Metoda koja je korišćena za ovaj istraživački projekat je deskriptivna metoda, koja se koristi za opisivanje i analiziranje fenomena, stanja ili karakteristika određene pojave ili grupe. Istraživačka tehnika koja je korišćena u ovom istraživačkom projektu je tehnika anketiranja. Instrument koji je korišćen za prikupljanje podataka je anketni list.. Ovaj instrument je dizajniran da omogući jednostavno i efikasno prikupljanje relevantnih podataka od ispitanika.

Predmet istraživanja

Predmet ovog istraživanja jeste analiza utjecaja sportskih aktivnosti na razvoj motoričkih sposobnosti djece predškolskog uzrasta. Poseban fokus stavljen je na različite vrste sportskih aktivnosti i njihov intenzitet u okviru predškolskih obrazovnih ustanova.

Cilj istraživanja

Glavni cilj ovog istraživanja je utvrditi na koji način i u kojoj mjeri planirane sportske aktivnosti doprinose razvoju motoričkih sposobnosti kod djece uzrasta od 3 do 5 godina. Također, istraživanjem se nastoji ukazati na mogućnosti unaprjeđenja postojećih programa fizičke aktivnosti u predškolskim ustanovama.

Hipoteze istraživanja

Na osnovu dosadašnjih teorijskih saznanja i praktičnih iskustava, postavljene su sljedeće hipoteze:

- Planirane sportske aktivnosti značajno doprinose razvoju motoričkih sposobnosti kod djece predškolskog uzrasta.
- Odgajatelji koji su stručno osposobljeni za provođenje sportskih aktivnosti efikasnije potiču razvoj motoričkih sposobnosti kod djece.
- Djeca koja redovno sudjeluju u sportskim aktivnostima postižu bolje rezultate u testovima motoričkih sposobnosti u odnosu na djecu koja nisu uključena u organizirane fizičke aktivnosti.

Značaj istraživanja

Rezultati ovog istraživanja mogu imati važnu primjenu u unaprjeđenju nastavnih programa i strategija fizičkog vaspitanja u predškolskim ustanovama. Također, oni mogu poslužiti kao osnov za kreiranje novih sportskih programa koji će biti prilagođeni potrebama i mogućnostima djece predškolskog uzrasta. Pored toga, istraživanje može doprinijeti podizanju svijesti o važnosti ranog uključivanja djece u sportske aktivnosti radi njihovog optimalnog razvoja.

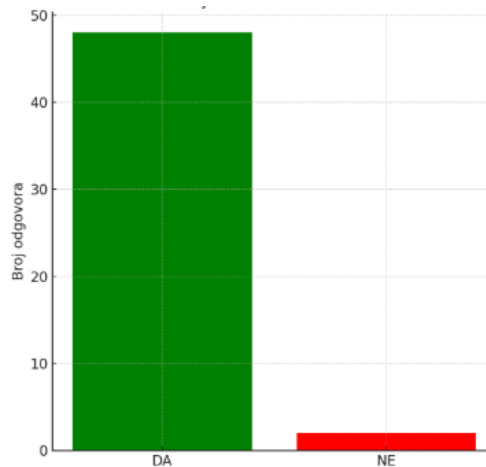
REZULTATI I DISKUSIJA

Podaci u Telama 1 i 2 mogu se analizirati i povezati kako bi se bolje razumio odnos između učitelja koji svakodnevno provode fizičku aktivnost s djecom i vremena koje izdvajaju za tu aktivnost. Tablica 1 prikazuje da većina učitelja svakodnevno provodi fizičku aktivnost s djecom, dok manji broj učitelja to ne prakticira. To znači da fizička aktivnost s djecom postaje redovita praksa u mnogim učiteljskim rutinama, što ukazuje na svijest o važnosti fizičke aktivnosti za razvoj djece.

Tabela 1. Da li svakodnevno vježbate neki oblik fizičke aktivnosti s djecom?

Table 1. Do you practice some form of physical activity with your children every day?

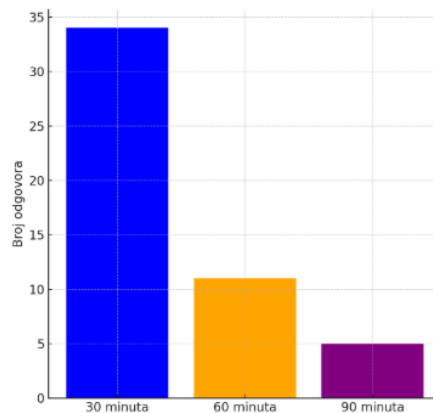
A) DA	48
B) NE	2



Grafikon 1. Svakodnevno vježbanje sa djecom u odgojnim ustanovama.
Graph 1. Daily exercise with children in educational institutions.

Tabela 2. Koliko vremena svakodnevno izdvajate za fizičku aktivnost djece?
Table 2. How much time do you allocate daily for children's physical activity?

A) 30 minuta	34
B) 60 minuta	11
C) 90 minuta	5



Grafikon 2. Koliko vremena svakodnevno izdvajate za fizičku aktivnost djece.
Chart 2. How much time do you allocate daily for children's physical activity.

Tablica 2 pokazuje da većina učitelja izdvajaju 30 minuta za fizičku aktivnost, dok manji broj njih izdvajaju 60 ili 90 minuta. Ova informacija pruža detaljniji uvid u količinu vremena koju učitelji ulažu u fizičke aktivnosti. Iako su učitelji većinom uključeni u fizičku aktivnost, razlike u trajanju aktivnosti (30 minuta u odnosu na 60 ili 90 minuta) mogu ukazivati na varijacije u pristupima i resursima za planiranje takvih aktivnosti. Korelacija između ovih podataka može se istražiti analizom koliko učitelji koji svakodnevno vježbaju s djecom također izdvajaju duže vrijeme za fizičke aktivnosti. Na primjer, moguće je da učitelji koji redovito prakticiraju fizičku aktivnost češće izdvajaju više vremena (60 ili 90 minuta) za fizičke aktivnosti, dok učitelji koji rjeđe provode aktivnosti s djecom, možda, izdvajaju samo 30 minuta. Kroz ovu korelaciju, može se doći do zaključka da učitelji koji prepoznaju važnost fizičke aktivnosti za djecu i svakodnevno je provode, skloni su ulagati i više vremena u te aktivnosti. Također, ovaj uvid može biti koristan za

Švraka, N. i sar. (2025). Sportske aktivnosti kao faktor razvoja motoričkih sposobnosti predškolske djece. *STED Conference 14(2)*, 433-441.

razumijevanje kako različiti faktori, kao što su motivacija učitelja ili dostupnost resursa, utječu na trajanje fizičkih aktivnosti u predškolskim ustanovama.

Tabela 3. Smatrate li da je fizička aktivnost važna za rast i razvoj djece?

Table 3. Do you think that physical activity is important for the growth and development of children?

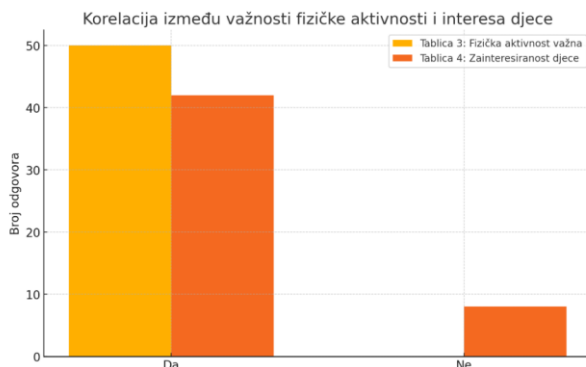
A) DA	50
B) NE	0

Tabela 4. Jesu li djeca zainteresirana za sudjelovanje u fizičkim aktivnostima?

Table 4. Are children interested in participating in physical activities?

A) DA	42
B) NE	8

U Tablici 3, svi ispitanici (50) smatraju da je fizička aktivnost važna za rast i razvoj djece. U Tablici 4, 42 ispitanika smatra da su djeca zainteresirana za sudjelovanje u fizičkim aktivnostima, dok 8 njih smatra da nisu. Korelacija između ovih podataka pokazuje da, unatoč tome što svi ispitanici smatraju fizičku aktivnost važnom, postoji mali broj onih koji smatraju da djeca nisu zainteresirana za fizičke aktivnosti. To može ukazivati na potrebu za dodatnim motiviranjem djece ili prilagođavanjem aktivnosti kako bi ih se angažiralo. Graf prikazuje broj odgovora za oba pitanja iz Tablica 3 i 4.



Grafikon 3. Korelacija važnosti tjelesne aktivnosti i interesa djece za vježbu.

Chart 3. Correlation of the importance of physical activity and children's interest in exercise.

Tabela 5. Koje vrste fizičke aktivnosti prakticirate u vašoj grupi?

Table 5. What types of physical activity do you practice in your group?

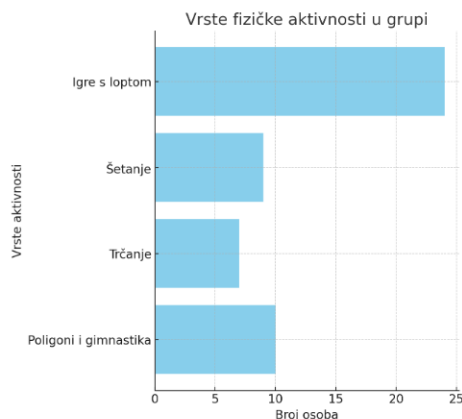
A) poligoni i gimnastika	10
B) trčanje	7
C) šetanje	9
D) igre s loptom	24

Tabela 6. Koju vrstu sportske aktivnosti prakticiraju dječaci?

Table 6. What type of sports activities do boys practice?

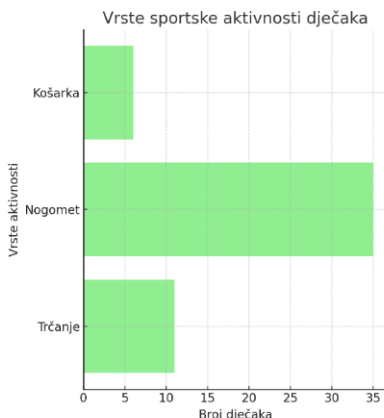
A) trčanje	11
B) nogomet	35
C) košarka	6

Grafikoni prikazuju vrste fizičkih aktivnosti koje se prakticiraju u grupama, prema Tablici 5, i vrste sportske aktivnosti koju prakticiraju dječaci, prema Tablici 6. U grupi, najpopularnija fizička aktivnost je "Igre s loptom" (24 osobe), dok su "Poligoni i gimnastika" najmanje zastupljeni sa 10 osoba.



Grafikon 4. Vrste dječijjih aktivnosti.
Chart 4. Types of children's activities.

Tablica 6: Među dječacima, najviše se prakticira "Nogomet" (35 dječaka), dok su "Košarka" (6 dječaka) i "Trčanje" (11 dječaka) manje zastupljeni.

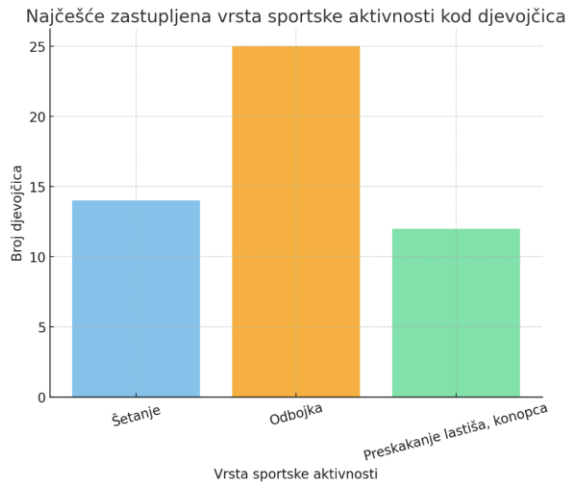


Grafikon 5. Vrste sportskih aktivnosti dječaka.
Chart 5. Types of boys' sports activities.

Iako podaci iz ove dvije tablice ne omogućuju izravnu korelaciju između aktivnosti u grupi i aktivnosti dječaka, možemo uočiti da fizičke aktivnosti u grupi i sportske aktivnosti dječaka dijele određene sličnosti, kao što je "Trčanje", koje se pojavljuje u obje tablice, ali u različitim brojevima. Aktivnost "Igre s loptom" se najviše prakticira u grupi, dok se kod dječaka najviše prakticira "Nogomet". Ovaj obrazac ukazuje na to da preferencije prema određenim vrstama aktivnosti mogu biti povezane s društvenim faktorima ili starosnim skupinama, ali za preciznu korelaciju potrebno je više podataka i analiza.

Tabela 7. Koja vrsta sportske aktivnosti je najčešće zastupljena kod djevojčica?
Table 7. What type of sports activity is most common among girls?

A) šetanje	14
B) odbojka	25
C) preskakanje lastiša, konopca	12



Grafikon 5. Vrste sportskih aktivnosti djevojčica.
Chart 5. Types of girls' sports activities.

Tabela 8. Dopustite li djeci da izaberu vrstu sportske aktivnosti?

Table 8. Do you allow children to choose the type of sports activity?

A) DA	42
B) ne	8

U analizi podataka koji se odnose na vrste sportskih aktivnosti koje najčešće prakticiraju djevojčice i dopuštanje djeci da biraju sport, cilj nam je razumjeti moguće međusobne povezanosti između tih dviju varijabli. Kroz ovaj rad, istražiti ćemo kako odgovori na pitanje o dopuštanju djeci da izaberu vrstu sportske aktivnosti mogu biti povezani s preferencijama djevojčica za određene sportske aktivnosti. Prvi skup podataka prikazuje vrste sportskih aktivnosti koje su najčešće zastupljene među djevojčicama. Prema podacima, odbojka je najpopularnija aktivnost, jer ju prakticira 25 djevojčica. Šetanje se javlja kao druga najzastupljenija aktivnost sa 14 djevojčica, dok preskakanje lastiša i konopca ima manju zastupljenost s 12 djevojčica. Ovi podaci ukazuju na to da su djevojčice sklonije kolektivnim aktivnostima poput odbojke, dok su aktivnosti poput šetanja i preskakanja konopca manje popularne.

Drugi skup podataka odnosi se na odgovor na pitanje dopuštaju li roditelji ili skrbnici djeci da samostalno odaberu sportsku aktivnost. Prema ovim podacima, 42 osobe (od ukupno 50 ispitanika) odgovaraju potvrdno, što znači da dopuštaju djeci slobodu izbora u vezi s vrstom sporta koji žele prakticirati. S druge strane, samo 8 osoba odgovara negativno, što implicira da neki roditelji ne dopuštaju djeci da biraju sport.

Iako na temelju samo ovih podataka ne možemo izravno izračunati korelaciju, možemo postaviti hipotezu o mogućim međusobnim vezama između dopuštanja djeci da biraju sportsku aktivnost i odabira sportske aktivnosti. Moguće je da roditelji koji dopuštaju djeci slobodan izbor aktivnosti imaju veću vjerojatnost da će djeca odabrati sportove poput odbojke, koji zahtijevaju timsku suradnju i organizirane sportske aktivnosti. Nasuprot tome, roditelji koji ne dopuštaju djeci da biraju aktivnosti mogu više poticati aktivnosti poput šetanja ili preskakanja konopca, koje su jednostavnije za organiziranje i mogu se prakticirati u kućnom okruženju ili u manjoj grupi.

Na temelju dostupnih podataka možemo pretpostaviti da postoji određena povezanost između slobode izbora sportskih aktivnosti i vrste sportova koje djeca preferiraju. Djeca koja imaju slobodu izbora možda će biti sklonija kolektivnim i timskim sportovima poput odbojke, dok ona koja nemaju ovu slobodu možda će prakticirati jednostavnije aktivnosti koje ne zahtijevaju organizaciju i timsku suradnju. Međutim, za precizniju analizu ove povezanosti potrebno je prikupiti dodatne podatke, poput demografskih informacija, kako bi se omogućila detaljnija korelacijska analiza. Bez dodatnih varijabli ili konkretnih individualnih podataka, ova analiza

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ostaje na razini hipoteza, a korelacija bi bila moguća tek uz dodatne podatke koji bi omogućili dublje razumijevanje odnosa između ovih dviju varijabli.

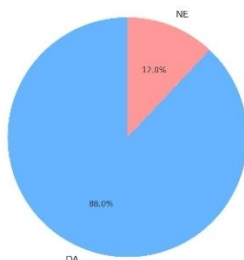
Tablica 9. Smatrate li da zainteresovanost djece za neki oblik fizičke aktivnosti zavisi od toga da li se roditelji bave sportom?

Table 9. Do you think that children's interest in some form of physical activity depends on whether their parents play sports?

A) DA	44
B) NE	6

Prema podacima iz ove tablice, 44 ispitanika smatra da zainteresiranost djece za fizičke aktivnosti zavisi od toga bave li se roditelji sportom (odgovor "DA"), dok se 6 ispitanika protivi ovoj tvrdnji (odgovor "NE").

Smatrate li da zainteresovanost djece za fizičku aktivnost zavisi od roditeljskog angažmana u sportu.



Grafikon 6. Zainteresiranost djece za fizičku aktivnost u odnosu na aktivnost roditelja.

Graph 6. Children's interest in physical activity in relation to their parents' activity.

Ovaj rezultat ukazuje na to da velika većina ispitanika vjeruje kako postoje određeni faktori koji utječu na interes djece za fizičke aktivnosti, među kojima su i roditeljski primjer i njihova uključenost u sport. Moguće je da roditelji koji se bave sportom svojim ponašanjem, navikama i stilom života prenose djeci pozitivan odnos prema tjelesnoj aktivnosti. Djeca koja imaju roditelje koji se redovito bave sportom možda će imati veću motivaciju za bavljenje fizičkim aktivnostima jer ih vide kao normalan i poželjan dio života.

S druge strane, manji broj ispitanika (6) smatra da interes djece za fizičku aktivnost nije povezan s time bave li se roditelji sportom. Moguće je da ovi ispitanici vjeruju da djeca mogu razviti vlastiti interes za fizičku aktivnost bez obzira na roditeljski primjer, ili pak smatraju da postoje drugi faktori koji imaju veći utjecaj na djecu, poput škole, prijatelja, medija i sličnih vanjskih utjecaja. Ova tablica pokazuje da postoji velika većina mišljenja koja povezuje zainteresiranost djece za fizičke aktivnosti s ponašanjem roditelja u vezi sa sportom. To sugerira da roditeljski primjer može igrati ključnu ulogu u razvoju sportskih navika i interesa kod djece. Za precizniju analizu, bilo bi korisno prikupiti dodatne podatke o demografskim karakteristikama ispitanika i njihovim obiteljskim okolnostima, što bi omogućilo dublje razumijevanje ovih povezanosti.

ZAKLJUČAK

Predškolsko obrazovanje predstavlja prvi segment obrazovnog sustava, gdje je od ključne važnosti već u ranom djetinjstvu osigurati djetetu prostor i vrijeme za kretanje i igru. Ovo omogućuje usvajanje pozitivnog stava prema tjelesnim aktivnostima i sportu, što može potaknuti stvaranje zdravih navika koje će trajati cijeli život. Jednako tako, neophodno je redovito analizirati i unapređivati opremljenost predškolskih ustanova za izvođenje sportskih aktivnosti. Programi fizičkih aktivnosti trebaju biti prilagođeni dječjim interesima i mogućnostima, a djeci treba pružiti slobodu izbora sporta kojim žele baviti. Na taj način omogućuje se razvijanje individualnih sklonosti, dok se istovremeno potiče ljubav prema sportu. Djeca pokazuju veliko zanimanje za

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sportske aktivnosti, a roditelji koji se bave sportom često izravno utječu na interes djece za određeni oblik tjelesne aktivnosti. Preko 70% ispitanih zaposlenika smatra da djeca pokazuju entuzijazam za sudjelovanje u sportskim programima. Rezultati istraživanja pokazuju da dječaci najčešće biraju košarku i nogomet, dok djevojčice preferiraju šetnju i odbojku.

Svi anketirani odgajatelji složili su se da tjelesna aktivnost pozitivno utječe na rast, razvoj te motoričke sposobnosti djece. Dobro osmišljeni sportski programi višestruko doprinose razvoju predškolske djece, uključujući kognitivni, socijalni i emocionalni aspekt razvoja. Današnji znanstveni i tehnološki napredak često dovodi do smanjene tjelesne aktivnosti, što je povezano s raznim zdravstvenim problemima. Brojne studije potvrđuju pozitivan utjecaj tjelesne aktivnosti na sveukupno zdravlje ljudi. Upravo zbog toga važno je već u predškolskom uzrastu uključiti djecu u sport. U ovom osjetljivom razvojnem razdoblju, može se značajno utjecati na stvaranje pozitivnih navika. S obzirom na činjenicu da djeca sve više vremena provode pred ekranima, u zatvorenom prostoru, ključno je da roditelji i odgajatelji prepoznaju važnost tjelesne aktivnosti i podupiru je. Fizičke sposobnosti djece imaju značajan utjecaj na njihovu svakodnevicu i opće blagostanje.

Kako bi se zadovoljile potrebe djece za kretanjem i omogućili optimalni uvjeti za rast i razvoj, važno je uključiti djecu u sportske programe što ranije. Dodatna fizička aktivnost pozitivno utječe na razvoj i usavršavanje motoričkih sposobnosti, čime se podiže ukupna kvaliteta života. Tjelesna aktivnost u predškolskoj dobi ključna je za cjelovit razvoj djeteta, osiguravajući temelj za zdrav život u budućnosti. Obrazovne ustanove, roditelji i društvena zajednica imaju zajedničku odgovornost osigurati djeci pristup kvalitetnim sportskim sadržajima i aktivnostima koje će im pomoći u izgradnji zdravih životnih navika te doprinijeti njihovom tjelesnom, emocionalnom i socijalnom razvoju.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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DEVELOPMENT OF MOTOR SKILLS IN PRESCHOOL CHILDREN UNDER THE INFLUENCE OF SPORTS ACTIVITIES

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ABSTRACT

Preschool institutions play a key role in laying the foundation for the overall development of a child, including physical, emotional, cognitive, and social aspects. Through various educational programs, special attention is given to physical activities that support the development of motor skills and the adoption of healthy lifestyle habits. Planned sports activities not only contribute to better physical fitness but also promote socialization, the development of discipline, and the creation of a positive self-image. The aim of this research was to analyze the frequency, type, and intensity of sports activities in preschool children during their stay in kindergarten, with a special focus on their motor skills. The research was conducted in a preschool institution in Mostar, where preschool educators were surveyed. Using a structured questionnaire, data were collected about the organization and implementation of sports activities and their impact on the development of children aged 3 to 5 years.

Keywords: development, motor skills, sports activities, preschool children.

OPTIMIZING TEACHING STRATEGIES IN LARGE GROUPS THROUGH MULTIPLICATIVE MCDM METHOD

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ABSTRACT

Delivering lectures in large student groups at higher education institutions, particularly at technical faculties, presents considerable pedagogical and organizational challenges. Individualized attention is significantly limited, making it difficult for instructors to adequately address the diverse learning needs of all students. Progressing too quickly may confuse students with insufficient background knowledge, while moving too slowly may demotivate advanced learners. Moreover, large class sizes reduce opportunities for interaction through questions, discussions, and active student participation.

This paper examines these challenges in the context of the Faculty of Technical Sciences Čačak, University of Kragujevac, where general education courses are delivered to large, multi-program groups, while professional courses in the later years are conducted in small, focused groups. The study presents a structured approach to evaluating the quality of the teaching process using the multiplicative MCDM method introduced by M. Žižović et al. (2016). A set of qualitative and quantitative criteria, including class size, has been defined and weighted based on expert assessments and student feedback. The results provide valuable insights into the effectiveness of current teaching practices and highlight specific areas for improvement, particularly in high-enrollment courses.

Keywords: Multi-criteria analysis, higher education, instructional strategies, large groups.

INTRODUCTION

In every multi-criteria decision-making process, several necessary steps are highlighted. First, it is necessary to clearly define the problem of multi-criteria decision-making (MCDM), as well as the goals to be achieved, that is, to identify and describe all relevant alternatives that participate in the process, and then to clearly define the criteria, attributes or performance indicators that will serve to evaluate the effectiveness of each alternative.

In order to evaluate the alternatives according to the criteria, it is necessary to conduct appropriate analyzes and collect data for the most objective assessment possible, and then to form a decision-making matrix in which the alternatives will be displayed in relation to the selected criteria. Furthermore, it is necessary to determine the weight coefficients for the criteria, using subjective methods (eg expert assessment) or objective methods (eg entropy method, CRITIC method). Finally, based on the obtained values, the alternatives are ranked using the appropriate MCDM method, and with the participation of all interested parties, experts and decision makers, the best alternative choice is determined.

Multi-criteria decision-making methods can be classified based on the way information is processed, the type of data required, the logic of decision-making, etc. It is known that the ELECTRE and PROMETHEE methods have found a wide range of applications because they are suitable for qualitative and quantitative criteria. They are based on mutual comparison of alternatives and their ranking based on the degree of preference. The AHP method makes it possible to solve complex problems in a structured way, provides transparency and a clear logical sequence of decisions, is intuitive and easy to apply. Distance-based methods, such as TOPSIS and VIKOR, evaluate alternatives based on their distance from the ideal and anti-ideal solutions, so

they are suitable for ranking problems because they emphasize closeness to the best and distance from the worst solution. With the development of mathematical models for the description of uncertainty and inaccuracy, fuzzy sets are applied in decision-making, so today various fuzzy MCDM methods are known, such as fuzzy AHP, fuzzy TOPSIS or fuzzy VIKOR, which enable more flexible modeling of preferences. Nowadays, methods based on artificial intelligence such as genetic algorithms, neural networks and evolutionary algorithms for multi-objective optimization are very popular since they are suitable for large and complex decision problems (Belton, & Stewart, 2002). Abrishamchi et al. (2005) state that selecting an appropriate multi-criteria decision-making method (MCDM) from a long list of available methods is itself a multi-criteria decision-making problem.

In this paper, we will present the multicriteria multicriteria decision-making method introduced by Žižović, Damljanović & Žižović (2016). The results presented in Žižović, Damljanović & Žižović (2017) and Žižović, Damljanović, Nikolić, & Vujičić. (2016) also serve as a foundation for this work.

MULTIPLIKATIVNA MCDM METODA

The multi-criteria decision-making (MCDM) problem can be described using a decision matrix, as shown in Table 1.

Suppose there are m alternatives, $A_1, A_2, \dots, A_m$, to be assessed based on n maximisation criteria, $K_1, K_2, \dots, K_n$. A decision matrix is an $m \times n$ -matrix with each element a_{ij} being the j -th criterion value of the i -th alternative; that is, a_{ij} is the degree in which alternative A_i satisfies criterion K_j ($0 \leq a_{ij} \leq 1$). Notice that we assume that all criteria are of the maximisation type (because all criteria of the minimisation type can be transformed into the maximisation type).

Table 1. Decision matrix.

	K_1	K_2	$\dots$	K_n
A_1	a_{11}	a_{12}	$\dots$	a_{1n}
A_2	a_{21}	a_{22}	$\dots$	a_{2n}
$\vdots$	$\vdots$	$\vdots$		$\vdots$
A_m	a_{m1}	a_{m2}		a_{mn}

In multiplicative multi-criteria method, each criterion K_j is associated with a degree of importance ρ_j ($0 < \rho_j \leq 1$) of the decision. Here, we assume that all the criteria are arranged in strictly descending order, in the sense that the first criterion has the greatest importance and each following criterion has less importance for the decision than the previous one.

Given a decision matrix for a particular multi-criteria problem, it is naturally assumed that all alternatives are usually efficient, there being no alternative dominated by any other. When an alternative is better according to one criterion, the other is better according to the other criterion. Therefore, incomparability holds for all pair-wise comparisons.

To decide which alternative is the best solution, it is necessary to have some additional piece of information on the preference relation of the decision-maker. For example, it can be a reference point or minimal suitable value. To develop a multiplicative model that describes the preference

relation, we use one hypothetical alternative $A(a_1, a_2, \dots, a_n)$, where $a_1, a_2, \dots, a_n$ are degrees in which hypothetical alternative A satisfies criteria $K_1, K_2, \dots, K_n$, respectively.

Each alternative A_i from the starting set of alternatives $\{A_1, A_2, \dots, A_m\}$ is compared with the hypothetical alternative A . Using appropriate calculation, its position with respect to this hypothetical alternative, whether it is better than the hypothetical alternative or not, is determined. Also, we calculate how much each alternative A_i is better or worse than the hypothetical alternative A and in that way we decide the final rank of alternatives from the starting set of alternatives $\{A_1, A_2, \dots, A_m\}$.

In a multiplicative multi-criteria value model, the decision-maker's preference relation on the set of alternatives is given by the function v_n which maps the set of alternatives $\{A_1, A_2, \dots, A_m\}$ into real numbers. For each alternative A_i , we have:

$$v_n(A_i) = \left(1 + \frac{a_{i1} - a_1}{a_1} \cdot \rho_1\right) \cdot \left(1 + \frac{a_{i2} - a_2}{a_2} \cdot \rho_2\right) \cdots \left(1 + \frac{a_{in} - a_n}{a_n} \cdot \rho_n\right). \quad (1)$$

This can be expressed as:

$$v_n(A_i) = \prod_{k=1}^n \left(1 + \frac{a_{ik} - a_k}{a_k} \cdot \rho_k\right). \quad (2)$$

If A_p and A_q are two alternatives from the starting set of alternatives $\{A_1, A_2, \dots, A_m\}$, then we say that alternative A_p is preferred over alternative A_q if and only if $v_n(A_p) > v_n(A_q)$. For this, we use the following notation:

$$A_p \succ A_q \Leftrightarrow v_n(A_p) > v_n(A_q). \quad (3)$$

If $v_n(A_p) = v_n(A_q)$ for two alternatives A_p and A_q , then we can omit the last criterion (which is the criterion of the lowest importance for the decision since all criteria are arranged in descending order) and the function v_{n-1} is given by:

$$v_{n-1}(A_i) = \prod_{k=1}^{n-1} \left(1 + \frac{a_{ik} - a_k}{a_k} \cdot \rho_k\right). \quad (4)$$

This procedure is repeated until the first (most important) criterion is taken into account.

TEACHING STRATEGIES IN LARGE GROUPS

Lectures at faculties in large groups of students represent a significant challenge, and at the same time bring several shortcomings in teaching. In large groups, it is difficult to provide individual attention to each student because the professor is not able to devote himself to each individual in the same way as in smaller groups. The teaching pace should be adjusted to meet the needs of all students. Progressing too quickly can confuse those who are not fully prepared, while progressing too slowly can bore more advanced students.

Also, in large groups, the opportunity for interaction between professors and students decreases. Questions, discussions and active participation of students in class are often reduced to a

minimum, and this can negatively affect the depth of understanding of the material. Less interaction and anonymity in groups can lead to passivity and less engagement, as students do not feel immediate responsibility or connection to the group.

In large groups, it can be challenging to maintain a high level of motivation among students. It is more difficult for professors to monitor the progress of all students, spot possible learning problems or clarify misunderstandings.

When students from different study programs are mixed, organizing group consultations and colloquiums becomes more complex. Different programs have different consultation needs, and coordinating times when all students are available can be nearly impossible.

Larger groups require more time to answer questions and solve problems with students. In such circumstances, professors make an extraordinary effort to ensure that all students are noticed and receive the help they need.

When classes include hundreds of students, teachers and teaching assistants are burdened with tasks that include checking and reviewing homework assignments, quizzes, tests, and exam notebooks. For the organization of exams in large groups, there is often not enough time to do everything efficiently, and oral exams are especially problematic because they can last longer than written ones.

This paper examines the aforementioned challenges in the context of the Faculty of Technical Sciences in Čačak, University of Kragujevac, where general education courses are taught in large, multi-program groups, while professional courses in the later years of study are conducted in small, focused groups. The results provide valuable insights into the effectiveness of existing teaching practices and indicate specific areas for improvement, especially in subjects with a large number of enrolled students. The set of criteria is given by Table 2.

Table 2. Criteria.

Kriterijum		Opis
K₁	Quality of individual attention	To what extent can the teacher devote himself to the individual? High in small groups, lower in large ones. In very small groups, the professional distance is too reduced.
K₂	Effectiveness of monitoring and evaluation	How realistic is it to organize an oral exam under the given conditions? How much time and resources does the assessment require?
K₃	Teacher workload	How long does it take to review assignments, tests and other activities? Larger groups mean more administrative burden.
K₄	Motivation and engagement	Does group size affect motivation and involvement? Small groups are more likely to encourage engagement.
K₅	Organization of consultations	Is it possible to organize group or individual consultations? Is the course easily adaptable to the number of students?
K₆	Quality of oral exams	Does the teacher have enough time to give each student a high-quality oral examination?
K₇	Involvement and interactivity	How actively can students participate in class? Is there room for discussion and questions?
K₈	Pragmatism and sustainability	Do all students receive the same material and information? One professor can impart knowledge to a large number of students, which saves the institution time and money.

Using method given in Žižović, Damjanović & Žižović (2017), we propose weighted coefficients by Table 3.

Table 3. Weighted coefficients.

ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	ρ_8
0.25	0.20	0.18	0.12	0.10	0.08	0.05	0.02

The set of alternatives is presented by Table 4, and the example of evaluation one criterion is given by Table 5.

Table 4. Alternatives.

Alternative	Veličina grupe	Opis
A_1	>300	Maximum group
A_2	241-300	Too large a group
A_3	181-240	Very large group
A_4	121-180	Larger group
A_5	61-120	Medium group
A_6	41-60	Small group
A_7	15-40	Very small group
A_8	<15	Minimum group

The other criteria were evaluated similarly (it is important to note that some criteria will have a different evaluation logic because, for example, for "Pragmaticity", larger groups may be better).

Taking into account all the previously defined parameters, the alternatives were evaluated according to the given criteria, and the resulting decision matrix for this model is presented in Table 6.

Table 5. Evaluation according to criterion K_1 .

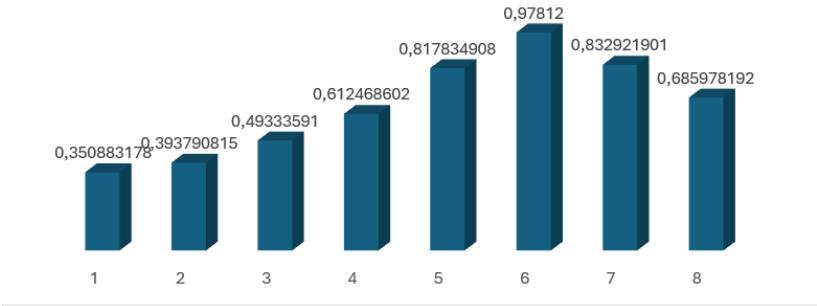
Veličina grupe	Ocena	Obrazloženje
>300	0.0	No individual attention at all.
241-300	0.1	Very little individual attention
181-240	0.3	Partially possible individual attention
121-180	0.5	Good individual attention
61-120	0.7	Very good individual attention
41-60	1.0	Excellent individual attention
15-40	0.8	Even better attention, but the risk of reducing the professional distance starts to appear
<15	0.6	Too small group – possibly too reduced professional distances

Table 6. Decision matrix of the model.

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
K_1	0.0	0.1	0.3	0.5	0.8	1.0	0.7	0.4
K_2	0.0	0.1	0.3	0.5	0.8	1.0	0.9	0.7
K_3	0.0	0.1	0.3	0.5	0.7	1.0	0.9	0.7
K_4	0.1	0.2	0.4	0.6	0.8	1.0	0.9	0.8
K_5	0.1	0.2	0.4	0.6	1.0	0.9	0.8	0.8
K_6	0.0	0.1	0.3	0.5	0.8	1.0	0.9	0.7
K_7	0.1	0.2	0.4	0.6	0.9	1.0	0.8	0.8
K_8	1.0	0.9	0.8	0.7	0.6	0.4	0.2	0.1

Table 7. Function v_n , for $n = 8$

$v_8(A_1)$	$v_8(A_2)$	$v_8(A_3)$	$v_8(A_4)$	$v_8(A_5)$	$v_8(A_6)$	$v_8(A_7)$	$v_8(A_8)$
0.350883	0.393791	0.493336	0.612469	0.817835	0.97812	0.832922	0.685978



Applying the method [3], we obtain the following ranking of alternatives:

$$A_6 \mapsto A_7 \mapsto A_5 \mapsto A_8 \mapsto A_4 \mapsto A_3 \mapsto A_2 \mapsto A_1$$

So the best alternative is A_6 .

CONCLUSION

Based on eight selected criteria and their relative weights, the analysis indicates that the optimal class size ranges from 41 to 60 students. This group size ensures sufficient individual attention without unnecessary over-personalization, enables effective monitoring and objective assessment, reduces the workload of instructors, making their work more sustainable, enhances student motivation and engagement, facilitates the organization of consultations and oral exams, and preserves interaction while encouraging active student participation. It avoids both extremes, not too large and not too small, remaining pragmatic and sustainable within the constraints of available resources and logistics.

It should be noted that many other criteria could be included in the analysis. However, the aim here is not to cover all ever possible aspects, but rather to demonstrate the methodology presented in the work of Žižović, Damljanović & Žižović (2016) through a concrete example.

This methodology can also be applied to the evaluation of class sizes at faculties outside the field of technical sciences, taking into account the specific characteristics of teaching in those contexts.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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THE CONCEPT AND SIGNIFICANCE OF ERGONOMICS IN HIGHER EDUCATION WITH A FOCUS ON MECHANICAL ENGINEERING

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ABSTRACT

Ergonomics constitutes an integral part of engineering design, specifically in the development of technical systems where human physical and cognitive characteristics are systematically considered. Higher education in mechanical engineering requires the structured integration of ergonomic principles into curricula, not only from a theoretical perspective but also in terms of their practical applicability in engineering practice. This paper aims to analyse the current role of ergonomics within university-level mechanical engineering education and to emphasize the necessity of aligning academic instruction with real-world industrial requirements. The implementation of ergonomic approaches in industrial settings contributes to the reduction of workload, enhancement of occupational safety, and optimization of productivity. Through the analysis of academic curricula, scientific literature, and professional standards, key areas of ergonomics education are identified, with a focus on the needs of contemporary mechanical engineering practice. The evaluation also includes the assessment of digital tools, simulation technologies, and hands-on projects that enable students to apply acquired knowledge to solve specific engineering problems. Furthermore, the paper discusses opportunities for interdisciplinary integration with fields such as manufacturing engineering, technical equipment design, and automation. The conclusion presents proposals for the adaptation of educational content and instructional methods, aiming to increase the practical relevance and effectiveness of ergonomics education in mechanical engineering programs.

Keywords: ergonomics, mechanical engineering, analysis, higher education.

INTRODUCTION

In mechanical engineering, ergonomics comprises principles and methods designed to adapt technical systems to human physiological, psychological, and cognitive characteristics. The goal is to optimize interaction between the operator, the machine, and the work environment. Higher technical education integrates ergonomic knowledge into student training to develop their abilities to design equipment and workplaces that respect anthropometric parameters, motor capabilities, sensory perception, and the operator's mental workload. (Aslanides et al, 2019; Górska et al, 2018) Industrial practice requires the systematic application of ergonomic principles, especially in the design of control elements, workplace component arrangement, selection of appropriate working postures, and minimizing the physical and mental strain on users. Rationalization of these aspects enables the reduction of operator errors, increased operational reliability of equipment, and extension of service life. Ergonomic solutions also consider the requirements of various user groups, specifics of the work environment, and the nature of the operated technologies. In automated and digitised production systems, it is essential to rigorously apply ergonomic criteria in the design of human-machine interfaces to ensure flawless, safe, and intuitive operation of technical devices. Education in this area includes methods of analysing workload within the work

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system, assessing working postures, handling operations, visual and informational demands, as well as identifying risk factors affecting the operator's long-term health. (Avila-Chaurand et al, 2019; Hignett et al, 2018) Integration of ergonomic principles into technical education in mechanical engineering allows for the optimization of design, construction, and operation of mechanical systems in terms of reliability, safety, efficiency, and sustainability of production processes. (Oakman et al. 2020; Järvelin-Pasanen et al., 2019) The presented article provides an analysis of selected pedagogical approaches to the education process of ergonomics abroad and within Slovakia.

ASSESSMENT OF ERGONOMICS IN HIGHER EDUCATION WITH A FOCUS ON MECHANICAL ENGINEERING - ABROAD

Two universities from the global ranking of the best universities offering study programs in ergonomics for mechanical engineering were selected: University of Nottingham (UK) – MSc Human Factors and Ergonomics and Universidad Nacional de Ingeniería (Peru) – Master of Specialization in Ergonomics. (QS World University Rankings, 2025)

Table 1. Technical comparison of Ergonomic Study programs - University of Nottingham and Ergonomics and Universidad Nacional de Ingeniería.

Criterion	Nottingham (UK)	Nacional de Ingeniería (Peru)
Duration	12/24 months	24 months
Form	online/in-person	In-person only
Language	English	Spanish
Accreditation	CIEHF (Chartered)	Professionally oriented, without CIEHF
Structure of module	Engineering ergonomics	Systemic ergonomic intervention

Study programs focused on ergonomics at the University of Nottingham (UK) and the Universidad Nacional de Ingeniería (Peru) represent two distinct approaches to professional education in this field. Despite several differences, they also exhibit common features that reflect the fundamental requirements and current trends in ergonomics as an interdisciplinary science. Differences are primarily observable in the mode of study delivery. The University of Nottingham offers both full-time and distance learning options with a duration of 12 or 24 months, providing significant flexibility, especially for international students and working professionals. In contrast, the program at the Universidad Nacional de Ingeniería is strictly delivered in a face-to-face format with a fixed duration of 24 months, requiring the physical attendance of students. The language of instruction also reflects the geographical and cultural orientation of both programs. While the British program is conducted in English, offering global accessibility and broader opportunities for international employment, the Peruvian program is delivered in Spanish, targeting primarily domestic applicants and the specific needs of the local labour market.

A fundamental distinction lies in the matter of accreditation. The program in Nottingham is certified by the CIEHF (Chartered Institute of Ergonomics and Human Factors), which enables graduates to obtain the internationally recognized status of "Chartered Ergonomist." In Peru, a comparable accreditation is lacking; however, the program is oriented towards the practical application of ergonomic principles within systemic interventions tailored to specific working conditions. The content structure of the programs also reveals different emphases. In the UK, the curriculum is modular, focusing on engineering ergonomics and technical applications, whereas in Peru, emphasis is placed on comprehensive systemic approaches and the implementation of solutions directly within organizational processes. Entry requirements also differ – Nottingham requires at least an upper second-class (2:1) honors degree in engineering or design, while in Peru, demonstrated professional experience in an engineering-related field is considered sufficient.

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Table 2. Advantages and disadvantages of Ergonomic Study programs - University of Nottingham and Ergonomics and Universidad Nacional de Ingeniería.

	University of Nottingham (UK)	Universidad Nacional de Ingeniería (Peru)
Advantages	International accreditation (CIEHF)	Strong practical focus on systemic ergonomic interventions
	Possibility of online study	Instruction in Spanish (advantage for the local market)
	Modular structure focused on technical ergonomics	Emphasis on applications in industrial environments
	Globally recognized "Chartered Ergonomist" title	Lower entry requirements (work experience sufficient)
	Instruction in English (advantage for global job market)	
Disadvantages	Higher entry education requirements	Lack of international accreditation (CIEHF)
	Higher tuition fees	Mandatory physical presence (without online options)
	English may be a barrier for non-English speakers	Limited applicability outside the Spanish-speaking market

Common features of the programs lie in their shared objective of preparing specialists capable of diagnosing and addressing ergonomic issues within the work environment. Both curricula emphasise an interdisciplinary approach that integrates technical, design, and human-centered aspects of ergonomics. The programs prepare graduates for the practical application of ergonomic principles with a focus on enhancing the safety, efficiency, and comfort of users of technical systems and workspaces. From a didactic and educational perspective, the study program at the University of Nottingham is characterised by a modern pedagogical style based on the integration of research and practice. Instruction includes simulations, laboratory work utilising virtual reality (VR), as well as methodologies such as design thinking and user-centered design. Students are guided towards conducting independent scientific research, culminating in the completion of a final research thesis.

Table 3. Educational assessment of Ergonomic Study programs - University of Nottingham and Ergonomics and Universidad Nacional de Ingeniería.

Criterion	Nottingham (UK)	UNI Peru
Teaching Methodology	Modern, combining research and practice, laboratory simulations, VR	Classical, lecture-based, industrial case studies
Focus	Human-Machine Interaction, cognitive and physical ergonomics	Work environment, Occupational Health and Safety (OHS), systemic interventions
Innovative Methods	Simulations, VR, design thinking, user-centred design	Minimal (traditional techniques, systems analysis)
Practical application	Product and technical system development, automotive/aerospace industries	Industrial working conditions, organizations, OHS
Independent Research	Mandatory scientific research project	Final exam / case study
Technological Equipment	Strong (VR systems, HCI laboratories)	Limited
Collaboration with industry	Industrial partners, real-world projects	Local enterprises, regional case studies

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The focus of the program at the University of Nottingham is primarily oriented towards Human-Machine Interaction (HCI), cognitive and physical ergonomics, as well as the development of technical systems and products applicable, for example, in the automotive and aerospace industries.

The university is equipped with state-of-the-art technological facilities, including HCI laboratories and VR systems. It collaborates with industrial partners on real-world projects, which significantly enhances the practical value of the study program. Another strong feature is the possibility of online learning and international CIEHF accreditation, which increases the global employability of graduates.

In contrast, the program at the Universidad Nacional de Ingeniería is based on a traditional lecture-driven approach, supplemented by case studies derived from industrial practice. Its primary focus is on systemic ergonomic interventions in the workplace, occupational health and safety (OHS), and the improvement of working conditions within enterprises and organizations. Innovative methods such as simulations or VR are practically not employed in this program; instruction is oriented towards conventional techniques such as systems analysis and workplace assessment. Students are required to develop a written case study with an emphasis on local conditions. Technological infrastructure is limited; however, there is cooperation with regional industries, enabling the practical application of acquired knowledge within the local industrial sector. Common features of both programs include an emphasis on the practical application of ergonomic knowledge and the development of an interdisciplinary perspective on human work within technical and industrial systems.

In both cases, the objective is to prepare specialists capable of solving ergonomic problems with the aim of improving efficiency, safety, and the quality of working life. The University of Nottingham program is suitable for those interested in an international career with a focus on technical and research-oriented ergonomics, whereas the Universidad Nacional de Ingeniería program primarily prepares professionals for practical roles in local industrial enterprises, with an emphasis on systemic solutions to ergonomic challenges.

ASSESSMENT OF ERGONOMICS IN HIGHER EDUCATION WITH A FOCUS ON MECHANICAL ENGINEERING - SLOVAKIA

In the context of Slovakia, "Ergonomics" does not exist as an independent study program, as is the case in the aforementioned foreign institutions, but rather constitutes an integral part of the educational curricula of various technical faculties. For the purpose of this evaluation, two faculties were selected – the Faculty of Manufacturing Technologies at the Technical University of Košice (FVT TUKE) and the Faculty of Materials Science and Technology at the Slovak University of Technology in Bratislava (MTF STU). (Internal documents FVT, 2025; internal documents MTF, 2025) These faculties were chosen to ensure the best possible comparability in terms of discipline, level of study, and faculty focus.

At the Faculty of Manufacturing Technologies of the Technical University of Košice, ergonomics education is delivered with an emphasis on the practical mastery of industrial ergonomics methods, aimed at the design and optimisation of workplaces, work systems, and processes. The course content focuses on the analysis of the human-machine-environment system using modern software tools for digital simulation of working conditions and physical workload, as well as the evaluation of workplace environmental parameters (such as noise and lighting). The educational process includes lectures and laboratory exercises, where students actively perform practical measurements under simulated conditions and subsequently process the collected data using specialized software. A significant component of the methodology is the digitalization of workplaces, which corresponds with Industry 4.0 trends. The practical component forms a substantial part of the course, thus preparing students for solving specific engineering tasks in real industrial environments.

The ergonomics instruction at the Faculty of Materials Science and Technology of the Slovak University of Technology in Bratislava is designed primarily as a theoretical-systemic discipline, with an emphasis on the application of ergonomics in the context of corporate occupational health

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and safety (OHS) management systems and the economic evaluation of ergonomic measures. The course content includes the fundamental principles of ergonomics, work standardization, statistical evaluation methods, and the development of ergonomic projects from a management perspective. An important part of the educational process involves teamwork on projects, preparation of presentations, and interpretation of ergonomic analysis results for corporate management. The practical component is represented mainly by case studies and the analysis of real production systems, without substantial use of measurement and simulation technology.

Table 4. Educational assessment of Ergonomic Study programs - Faculty of Manufacturing Technologies and Faculty of Materials Science and Technology in Trnava.

Criterion		TUKE - Faculty of Manufacturing Technologies	STU – Faculty of Materials Science and Technology in Trnava
Focus		Industrial ergonomics, Human-Machine-Environment systems	OHS, enterprise programs, standardization
Methodology		Laboratory measurements, software analysis, Industry 4.0 tools	Theoretical preparation, presentations, legislative approach
Practical/Software use		High – software support (modelling of noise, lighting, workload)	Lower – emphasis on system evaluation and regulations
Examination		Combination of continuous assessment + practical outputs	Written exam 80%, 20% team projects
Real Problem Solving		Industrial cases, digital checklists	Mainly conceptual (cost/benefit), fewer specific measurements
Preparation for Practice		Direct contact with industrial environment	Managerial approach to OHS, system planning
Teamwork		Less emphasis	Significant part of education

From a methodological perspective, the Faculty of Manufacturing Technologies favors an experimental, technical-application approach, whereas the Faculty of Materials Science and Technology emphasizes systemic and managerial aspects of ergonomics implementation. This distinction is reflected in the pedagogical process through a differing proportion of practical instruction – while students in Košice solve specific tasks using digital tools and real-world measurements, in Bratislava, analytical and evaluative methods dominate, focusing on corporate environments and applicable legislation. Both approaches have their justification – the model of the Faculty of Manufacturing Technologies is particularly suitable for future technologists and industrial engineers who will be engaged in the design and optimization of workplaces and production systems. Conversely, the approach of the Faculty of Materials Science and Technology is aimed at preparing ergonomic specialists and occupational health and safety (OHS) managers capable of implementing ergonomic principles at the level of corporate management and optimizing work processes in accordance with legislative requirements and economic criteria.

A significant finding of this comparison is the fact that ergonomics education at both institutions reflects current trends and practical needs – the model of the Faculty of Manufacturing Technologies integrates the requirements of Industry 4.0, while the approach of the Faculty of Materials Science and Technology develops a systemic and value-oriented perspective on ergonomics as part of corporate management. From a didactic point of view, both approaches can be considered complementary, resulting in the preparation of graduates capable of meeting a broad spectrum of labour market demands in the fields of ergonomics and industrial engineering.

Assessment of the Use of Digital Tools, Simulation Technologies, and Practical Assignments in Ergonomics Education

In the context of the utilization of digital tools, simulation technologies, and practical assignments, this comparison focuses on the approach to ergonomics education at the Faculty of Manufacturing Technologies, Technical University of Košice (FVT TUKE), and the Faculty of Materials Science and Technology, Slovak University of Technology in Bratislava (MTF STU), alongside selected international universities — the University of Nottingham (UK) and Universidad Nacional de Ingeniería (Peru). The comparison primarily examines the use of digital tools, simulation technologies, practical exercises, and teaching methodologies, as well as the characterisation of students' practical preparation for real industrial environments.

Table 5. Educational assessment of Ergonomic Study programs - Faculty of Manufacturing Technologies and Faculty of Materials Science and Technology in Trnava.

Category	TUKE - Faculty of Manufacturing Technologies	STU – Faculty of Materials Science and Technology in Trnava	Nottingham (UK)	UNI Peru
Digital Simulations	Software modeling, Industry 4.0	Minimal	VR, HCI, simulations	Almost none
Real Measurements	Noise, lighting, load	None	HCI labs, VR tests	System analysis
Team Tasks/Projects	Partially	Significant	Individual and group	System projects
OHS/System Ergonomics	Partial	Dominant	Supplementary	Main focus
Industry Practice	Model tasks	Case studies	Industrial partnerships	Field visits

At FMT TUKE, the methodology for teaching the course "Ergonomics" is based on a combination of theoretical preparation and practical laboratory measurements, strongly supported by software simulation tools. Students work with specialised software for modelling and analysing noise, lighting, and physical workload, aligning with the requirements of industrial engineering within the Industry 4.0 framework. The course enables the application of knowledge in ergonomic design, rational work organisation, and workplace optimisation directly through practical assignments, enhancing student readiness for real industrial production conditions.

At STU, the "Ergonomics" course is oriented towards theoretical and systemic aspects, with emphasis on legislative requirements, risk assessment, and the economic efficiency of ergonomic interventions. The practical component is implemented through team projects, case studies, and preparation of analytical presentations. However, direct use of experimental measurements or modern simulation technologies is lacking, which may limit students' applied skills in physical ergonomics and digital workplace design.

At the University of Nottingham, ergonomics education is delivered at a high technological level, routinely employing simulation and virtual reality (VR) tools, as well as laboratory Human-Computer Interaction (HCI) equipment. Students actively participate in research projects, and their training includes solving real industrial cases in direct collaboration with industry partners. The curriculum is designed so that graduates master modern methods of work system design and product design from a human interaction perspective.

At the Universidad Nacional de Ingeniería in Peru, the "Ergonomics" course focuses primarily on systemic assessment of the work environment and occupational safety in the context of the local industry. The course has a traditional character with an emphasis on case studies and site visits but without significant use of digital simulation tools or advanced laboratory technologies. This educational approach equips students with the ability to analyse and improve

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work systems from organisational and systemic perspectives, but does not provide the technical skills necessary for detailed ergonomic modelling.

From the perspective of pedagogical practice, it is evident that Slovak institutions (FVT TUKE and MTF STU) integrate ergonomics into broader industrial engineering study programs, without offering an independent ergonomics program at the second-cycle level, unlike selected foreign universities. Abroad, ergonomics is taught within accredited specialized study programs (e.g., MSc Human Factors and Ergonomics), enabling comprehensive education, including research and specialization.

From a professional viewpoint, it can be concluded that the University of Nottingham employs the most advanced technologies in ergonomics education, dominated by VR and HCI simulations. FVT TUKE emphasizes practical education with a focus on Industry 4.0 and digitalization. MTF STU prioritizes systemic and economic evaluation within occupational health and safety (OHS), while UNI Peru prefers a traditional approach focused on operational conditions without significant technological support.

CONCLUSIONS

Analysis of Ergonomics Education in the Field of Mechanical Engineering Confirms the Importance of Systematic Integration of Ergonomic Principles into Higher Education with Emphasis on Practical Application. Foreign programs (Nottingham, UNI Peru) offer specialized curricula with differing focuses — technical-engineering versus systemic-interventional approaches. In Slovakia, ergonomics is incorporated within broader study programs with varied methodologies — TUKE utilizes digital tools and practical simulations, whereas STU emphasizes systemic and managerial aspects. Both concepts address practical needs; however, a standalone study program in Ergonomics is currently absent. For the future, it is advisable to consider establishing an independent accredited study program titled “Ergonomics in Mechanical Engineering,” which would integrate both technical-application and systemic-managerial approaches with a focus on digital technologies (VR, HCI, simulations) and Industry 4.0. Such a program would strengthen the preparation of specialists capable of comprehensively addressing ergonomic challenges in modern manufacturing systems and enhance graduates' competitiveness in the international labour market.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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OTHER TOPICS
OSTALE TEME

ON SOLVING HAMILTON'S GENERAL QUADRATIC EQUATION

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ABSTRACT

Based on *Hamilton's* method of solving the quadratic equation (couple equation), defined over the field of couple numbers, as he calls them, in this paper the method of solving the general Hamilton quadratic equation is reduced to solving of the matrix quadratic equation, which is defined over the field of bireal matrices, which correspond to bireal numbers. As the matrix equation is decomposed into a system of nonlinear algebraic equations (SNAE), the solutions of the matrix equation are also the solutions of the SNAE, such that the solutions of the matrix quadratic equation implicitly determine the symmetric matrices S of the null space of the SNAE. In the second part of the paper, the matrix method for solving the SNAE, which is obtained via decomposition of *Hamilton's* quadratic equation

$$(a_{11}, a_{21})(x, 0)^2 - (a_{12}, a_{22})(0, y)^2 + 2(b_2, -b_1)(x, 0)(0, y) + (c_{11}, c_{21})(x, 0) + (c_{22}, -c_{12})(0, y) + (d_1, d_2) = (0, 0).$$

Keywords: bireal numbers, couple equation, matrix quadratic equation.

INTRODUCTION

In the middle of the 19th century, on the basis of the previously defined product of ordered pairs of real numbers (number couples) (Hamilton, 1837, Hamilton, 1853), as follows

$$(a, b)(c, d) = (ac - bd, ad + bc), \quad (1)$$

the process of solving the quadratic equation (couple equation)

$$(x, y)^2 + (b, 0)(x, y) + (c, 0) = (0, 0), \quad (2)$$

Hamilton reduced to solving an ordinary quadratic equation $x^2 + bx + c = 0$. More precisely, *Hamilton* reduced the process of solving the equation (1) to the process of solving a system of two separate equations

$$x^2 - y^2 + bx + c = 0 \text{ and } 2xy + by = 0, \quad (3)$$

which always allows real solutions, regardless of whether the discriminant $b^2/4 - c$ is a positive or negative real number, (Hamilton, 1853). In the first case, $y = 0$ in the second equation of the system, which leads us to the first solution

$$(x, y) = \left(-\frac{b}{2} \pm \sqrt{\frac{b^2}{4} - c}, 0\right). \quad (4)$$

In the second case, the second factor $2x + b$, in the second equation of system (3), should be equalized to zero and thus reach another solution

$$(x, y) = \left(-\frac{b}{2}, \pm \sqrt{c - \frac{b^2}{4}}\right). \quad (5)$$

On the other hand, systems of nonlinear algebraic equations (SNAE), to which system (3) itself belongs, are more ubiquitous in many numerous applications. Solving SNAE, in general, requires numerical simulation, and increasingly robust and efficient methods for solving SNAE are continuously sought. At the end of the last century, as well as at the beginning of this century, the so-called method of neural networks was imposed, (Goulianas et al., 2013, Li & Zhezhaio, 2008, Margaritis & Goulianas, 2012). In (Borisevich et al., 2000) an overview of existing algorithmic approaches for solving SNAE: reduction to *Grebner's* basis, the multidimensional resulting method and the spectral method. In addition, it is shown that the problem of solving SNAE is equivalent to the problem of finding a rank 1 matrix in a given subspace of a space of matrices. All of these methods start from a system of k nonlinear algebraic equations ($k \geq 1$) with n unknowns x_i , which are elements of the $n \times 1$ column matrix $\mathbf{x} = (x_i)^T = [x_1 \ x_2 \ \dots \ x_n]^T$ ($n \geq 2$), as follows

$$\sum_{i=1}^n \sum_{j=1}^n (a_{ij})_k x_i x_j + 2 \sum_{i=1}^n (b_i)_k x_i + c_k = 0. \quad (6)$$

In the matrix notation of system (6)

$$\mathbf{x}^T A_k \mathbf{x} + 2 \mathbf{b}_k^T \mathbf{x} + c_k = 0, \quad (7)$$

the $n \times n$ matrices $A_k = (a_{ij})_k$ are symmetric matrices, $\mathbf{b}_k^T = (b_i)_k^T$ are $1 \times n$ row matrices and c_k are constants. Let $\hat{A}_k$ denote the accompanying square symmetric matrices of higher order by 1 of the matrices A_k , obtained by bordering the matrices A_k on the right and from below by the column matrices $(\mathbf{b}_k^T, c_k)^T$ and the row matrices $(\mathbf{b}_k^T, c_k)$. The null space of system (6) is a set L_0 of all symmetric square matrices S of order $n + 1$ satisfying a system of equalities for traces

$$\text{tr}(\hat{A}_k S) = 0. \quad (8)$$

Theorem 1. which follows, and is taken from (Borisevich et al., 2000), allows for simplification in the solving of some concrete systems of type (6).

Theorem 1. For each ordered set of numbers $s_1, s_2, \dots, s_n$, the system matrix S may be formed as $S = [s_1 \ s_2 \ \dots \ s_n \ 1]^T [s_1 \ s_2 \ \dots \ s_n \ 1]$ that provides the one-to-one correspondence between all solutions of system (6) and the set of all affine matrices of rank 1 of zero-space of system (6).

As emphasized in (Borisevich et al., 2000), for the practical use of *Theorem 1.*, it is enough to determine a basis $E_1, E_2, \dots, E_q$ of the null space L_0 of the system (6). The problem of solving system (6) is equivalent to the problem of searching all such numbers $\alpha_1, \alpha_2, \dots, \alpha_q$, for which the matrices $\alpha_1 E_1 + \alpha_2 E_2 + \dots + \alpha_q E_q$ are affine matrices of rank 1.

In (Bardell, 2014) and (Hardy, 2008), an explicit (qualitative) analysis of solutions of SNAE (6), in the case where $n = k = 2$, was presented. This type of system (6) is obtained via decomposition of *Hamilton's* general quadratic equation

$$(a_1, a_2)(x, y)^2 + (b_1, b_2)(x, y) + (c_1, c_2) = (0, 0). \quad (9)$$

This paper brings an implicit method for solving this type of SNAE (5), which is based on solving a matrix quadratic equation

$$AX^2 + BX + C = O, \quad (10)$$

$$\text{where } A = \begin{bmatrix} a_1 & a_2 \\ -a_2 & a_1 \end{bmatrix}, B = \begin{bmatrix} b_1 & b_2 \\ -b_2 & b_1 \end{bmatrix}, C = \begin{bmatrix} c_1 & c_2 \\ -c_2 & c_1 \end{bmatrix}, X = \begin{bmatrix} x & y \\ -y & x \end{bmatrix} \text{ and } O \text{ is}$$

a square zero matrix. The matrix quadratic equation (10) corresponds to the quadratic equation (9). In the second part of the paper, the matrix method for solving the SNAE is presented, which is obtained via decomposition of the following *Hamilton's* quadratic equation (couple equation)

$$(a_{11}, a_{21})(x, 0)^2 - (a_{12}, a_{22})(0, y)^2 + 2(b_2, -b_1)(x, 0)(0, y) + (c_{11}, c_{21})(x, 0) + (c_{22}, -c_{12})(0, y) + (d_1, d_2) = (0, 0). \quad (11)$$

SOLUTIONS OF HAMILTON'S GENERAL QUADRATIC EQUATION

Solutions of quadratic equations $ax^2 + bx + c = 0$, over the field of real numbers $\mathbb{R}$, exist if the discriminant of the system $\Delta = b^2 - 4ac$ is nonnegative. On the other hand, the elements w of the field $\mathbb{R}^2$ (the *Cartesian* square of the set of real numbers $\mathbb{R}$) are ordered pairs (x, y) of real numbers (*Hamilton's* number couples), which we can rename bireal numbers. As $(x, y) = x(1, 0) + y(0, 1)$, where $(1, 0)$ and $(0, 1)$ are the basis elements of the field of bireal numbers $\mathbb{R}^2$ (Hamilton, 1837), the quadratic equation, over the field of bireal numbers $\mathbb{R}^2$,

$$(a_1, a_2)w^2 + (b_1, b_2)w + (c_1, c_2) = (0, 0), \quad (12)$$

where $w = (x, y)$, can be decomposed, such that

$$\begin{aligned} (a_1, a_2)w^2 + (b_1, b_2)w + (c_1, c_2) &= a_1w^2 + b_1w + (c_1, 0) + a_2ww_{\perp} + b_2w_{\perp} + (0, c_2) = \\ &= [a_1w^2 + b_1w + (c_1, 0)](1, 0) + [a_2w^2 + b_2w + (c_2, 0)](0, 1) = (0, 0), \end{aligned} \quad (13)$$

where $w_{\perp} = (0, 1)w$ is the bireal number $(-y, x)$, which is obtained by rotating the bireal number w , by an angle of $\pi/2$ radians, in the positive mathematical direction.

Between the elements w of the field of bireal numbers $\mathbb{R}^2$ and square matrices of the second order $\begin{bmatrix} x & y \\ -y & x \end{bmatrix}$, which are the elements of the field of bireal matrices $\mathbb{R}^2$, whose basis consists of

the identity matrix $E = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ and the antisymmetric matrix $\hat{E} = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$, there is a one-to-

one correspondence. Accordingly, the product of bireal numbers (1) corresponds to the product of the corresponding bireal matrices and vice versa

$$(a, b)(c, d) \square \begin{bmatrix} a & b \\ -b & a \end{bmatrix} \begin{bmatrix} c & d \\ -d & c \end{bmatrix} = \begin{bmatrix} ac - bd & ad + bc \\ -(ad + bc) & ac - bd \end{bmatrix} \square (ac - bd, ad + bc). \quad (14)$$

The inverse bireal number w^{-1} ($w \neq (0,0)$) corresponds to the inverse matrix $\begin{bmatrix} x & y \\ -y & x \end{bmatrix}^{-1}$, so that

$$w^{-1} = \frac{\bar{w}}{\|w\|^2} \square \frac{1}{x^2 + y^2} \begin{bmatrix} x & -y \\ y & x \end{bmatrix}, \quad (15)$$

where $\|w\| = (x^2 + y^2)^{1/2}$ is the *Euclidean* norm of $\mathbb{R}^2$ and $\bar{w} = (x, -y)$. Since $X = xE + y\hat{E}$, *Hamilton's* the general quadratic equation (9), in matrix form, obtained from the matrix equation (10), is as follows

$$\begin{aligned} AX^2 + BX + C &= \begin{bmatrix} a_1(x^2 - y^2) - 2a_2xy & a_2(x^2 - y^2) + 2a_1xy \\ -[a_2(x^2 - y^2) + 2a_1xy] & a_1(x^2 - y^2) - 2a_2xy \end{bmatrix} + \begin{bmatrix} b_1x - b_2y & b_1y + b_2x \\ -(b_1y + b_2x) & b_1x - b_2y \end{bmatrix} + \\ &+ \begin{bmatrix} c_1 & c_2 \\ -c_2 & c_1 \end{bmatrix} = a_1 \begin{bmatrix} x^2 - y^2 & 2xy \\ -2xy & x^2 - y^2 \end{bmatrix} + b_1 \begin{bmatrix} x & y \\ -y & x \end{bmatrix} + c_1 E + \\ &+ a_2 \begin{bmatrix} -2xy & x^2 - y^2 \\ -(x^2 - y^2) & -2xy \end{bmatrix} + b_2 \begin{bmatrix} -y & x \\ -x & -y \end{bmatrix} + c_2 \hat{E} = O, \end{aligned} \quad (16)$$

So that $AX^2 + BX + C = (a_1X^2 + b_1X + c_1E)E + (a_2X^2 + b_2X + c_2E)\hat{E} = O$.

According to (13), that is (16), the field of bireal matrices $\{X : \hat{E}Y_i = Y_i\} \subset \mathbf{R}^2$, where $Y_i: \mathbf{R}^2 \rightarrow \mathbf{R}^2$ ($i = 1, 2$) are square matrix functions $a_iX^2 + b_iX + c_iE$, is the null field L_0 (the set of solutions) of the matrix quadratic equation (16). Obviously, according to *Theorem 1.*, the real numbers $s_1 = x$ and $s_2 = y$, where x and y are elements of the bireal matrices $X \in L_0$, are elements of the matrices $[s_1 \ s_2 \ 1]$, such that the matrices $S = [s_1 \ s_2 \ 1]^T [s_1 \ s_2 \ 1]$ are symmetric matrices of the null space of SNAE

$$\begin{aligned} \sum_{i=1}^2 \sum_{j=1}^2 (a_{ij})_1 x_i x_j + 2 \sum_{i=1}^2 (b_i)_1 x_i + c_1 &= 0 \\ \sum_{i=1}^2 \sum_{j=1}^2 (a_{ij})_2 x_i x_j + 2 \sum_{i=1}^2 (b_i)_2 x_i + c_2 &= 0, \end{aligned} \quad (17)$$

which can be written in a more concise form

$$\mathbf{x}^T A_1 \mathbf{x} + 2\mathbf{b}_1^T \mathbf{x} + \frac{c_1}{a_1} = 0 \quad \mathbf{x}^T A_2 \mathbf{x} + 2\mathbf{b}_2^T \mathbf{x} + \frac{c_2}{a_2} = 0, \quad (18)$$

where $\mathbf{x}^T = [x_1 \ x_2] = [x \ y]$,

$$A_1 = \begin{bmatrix} a_{11}^{(1)} & a_{12}^{(1)} \\ a_{21}^{(1)} & a_{22}^{(1)} \end{bmatrix} = \begin{bmatrix} 1 & -\frac{a_2}{a_1} \\ -\frac{a_2}{a_1} & -1 \end{bmatrix}, A_2 = \begin{bmatrix} a_{11}^{(2)} & a_{12}^{(2)} \\ a_{21}^{(2)} & a_{22}^{(2)} \end{bmatrix} = \begin{bmatrix} 1 & \frac{a_1}{a_2} \\ \frac{a_1}{a_2} & -1 \end{bmatrix},$$

$$\mathbf{b}_1^T = \begin{bmatrix} b_1^{(1)} & b_2^{(1)} \end{bmatrix} = \begin{bmatrix} \frac{b_1}{2a_1} & -\frac{b_2}{2a_1} \end{bmatrix} \text{ and } \mathbf{b}_2^T = \begin{bmatrix} b_1^{(2)} & b_2^{(2)} \end{bmatrix} = \begin{bmatrix} \frac{b_2}{2a_2} & \frac{b_1}{2a_2} \end{bmatrix}.$$

By (8), matrices S are affine matrices of rank 1, which satisfy a system of equalities for traces

$$\text{tr}(\hat{A}_1 S) = 0 \text{ and } \text{tr}(\hat{A}_2 S) = 0, \quad (19)$$

$$\text{where } \hat{A}_1 = \begin{bmatrix} 1 & -\frac{a_2}{a_1} & \frac{b_1}{2a_1} \\ -\frac{a_2}{a_1} & -1 & -\frac{b_2}{2a_1} \\ \frac{b_1}{2a_1} & -\frac{b_2}{2a_1} & \frac{c_1}{a_1} \end{bmatrix} \text{ and } \hat{A}_2 = \begin{bmatrix} 1 & \frac{a_1}{a_2} & \frac{b_2}{2a_2} \\ \frac{a_1}{a_2} & -1 & \frac{b_1}{2a_2} \\ \frac{b_2}{2a_2} & \frac{b_1}{2a_2} & \frac{c_2}{a_2} \end{bmatrix}.$$

On the other hand, the solutions of system (17) are the solutions of matrix equation (16). Since bireal matrices, if they are not zero matrices, are regular and commutative matrices, bireal matrices

$$X_1 = -\frac{A^{-1}B}{2} + \sqrt{\left(\frac{A^{-1}B}{2}\right)^2 - A^{-1}C} \text{ and } X_2 = -\frac{A^{-1}B}{2} - \sqrt{\left(\frac{A^{-1}B}{2}\right)^2 - A^{-1}C}, \quad (20)$$

are solutions of the matrix equation (16). Considering the fact that

$$A^{-1}B = \frac{1}{a_1^2 + a_2^2} \begin{bmatrix} a_1 & -a_2 \\ a_2 & a_1 \end{bmatrix} \begin{bmatrix} b_1 & b_2 \\ -b_2 & b_1 \end{bmatrix} = \frac{1}{a_1^2 + a_2^2} \begin{bmatrix} a_1 b_1 + a_2 b_2 & a_1 b_2 - a_2 b_1 \\ a_2 b_1 - a_1 b_2 & a_1 b_1 + a_2 b_2 \end{bmatrix},$$

$$A^{-1}C = \frac{1}{a_1^2 + a_2^2} \begin{bmatrix} a_1 & -a_2 \\ a_2 & a_1 \end{bmatrix} \begin{bmatrix} c_1 & c_2 \\ -c_2 & c_1 \end{bmatrix} = \frac{1}{a_1^2 + a_2^2} \begin{bmatrix} a_1 c_1 + a_2 c_2 & a_1 c_2 - a_2 c_1 \\ a_2 c_1 - a_1 c_2 & a_1 c_1 + a_2 c_2 \end{bmatrix}$$

$$\text{and } (A^{-1}B)^2 = \frac{1}{(a_1^2 + a_2^2)^2} \begin{bmatrix} (a_1^2 - a_2^2)(b_1^2 - b_2^2) + 4a_1 a_2 b_1 b_2 & 2[(a_1^2 - a_2^2)b_1 b_2 - (b_1^2 - b_2^2)a_1 a_2] \\ 2[(b_1^2 - b_2^2)a_1 a_2 - (a_1^2 - a_2^2)b_1 b_2] & (a_1^2 - a_2^2)(b_1^2 - b_2^2) + 4a_1 a_2 b_1 b_2 \end{bmatrix},$$

$$\text{the bireal matrix } D^2 = \begin{bmatrix} d_1^2 - d_2^2 & 2d_1 d_2 \\ -2d_1 d_2 & d_1^2 - d_2^2 \end{bmatrix}, \text{ whose elements satisfy SNAE}$$

$$\begin{aligned} d_1^2 - d_2^2 &= \frac{(a_1b_1 + a_2b_2)^2 - (a_1b_2 - a_2b_1)^2 - 4(a_1^2 + a_2^2)(a_1c_1 + a_2c_2)}{4(a_1^2 + a_2^2)^2} \\ 2d_1d_2 &= \frac{2(a_1b_1 + a_2b_2)(a_1b_2 - a_2b_1) - 4(a_1^2 + a_2^2)(a_1c_2 - a_2c_1)}{4(a_1^2 + a_2^2)^2}, \end{aligned} \quad (21)$$

is the matrix discriminant of the matrix equation (16). SNAE (21) can be solved graphically and analytically. Clearly, the graphic solution is the coordinates of the points of intersection of two second order curves, as shown in Figure 1

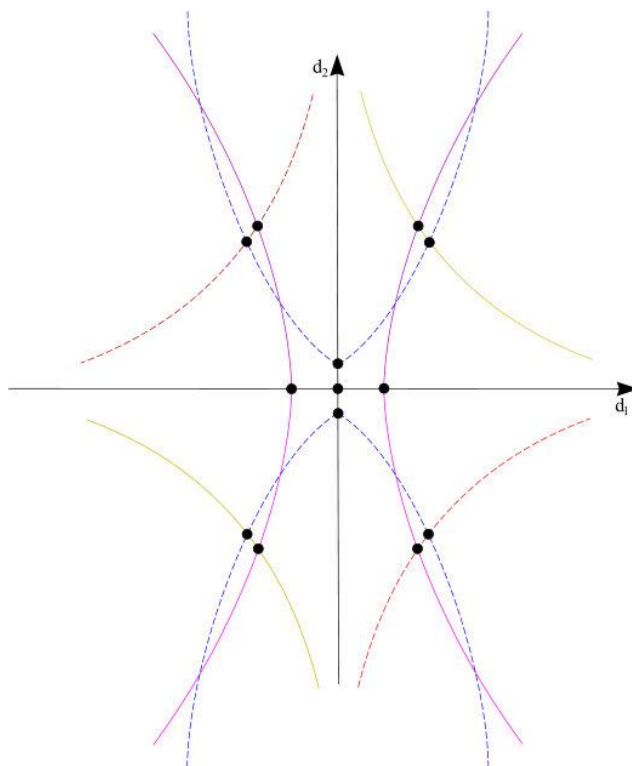


Figure 1.

On the other hand, the analytical solution can be obtained by converting *Cartesian* coordinates into polar coordinates

$$d_1 = r \cos \varphi \text{ and } d_2 = r \sin \varphi. \quad (22)$$

Therefore, in polar coordinates

$$\begin{aligned} r^2 \cos 2\varphi &= \frac{(a_1b_1 + a_2b_2)^2 - (a_1b_2 - a_2b_1)^2 - 4(a_1^2 + a_2^2)(a_1c_1 + a_2c_2)}{4(a_1^2 + a_2^2)} \text{ and} \\ r^2 \sin 2\varphi &= \frac{2(a_1b_1 + a_2b_2)(a_1b_2 - a_2b_1) - 4(a_1^2 + a_2^2)(a_1c_2 - a_2c_1)}{4(a_1^2 + a_2^2)}. \end{aligned} \quad (23)$$

$$\text{that is, } \tan 2\varphi = \frac{2(a_1b_1 + a_2b_2)(a_1b_2 - a_2b_1) - 4(a_1^2 + a_2^2)(a_1c_2 - a_2c_1)}{(a_1b_1 + a_2b_2)^2 - (a_1b_2 - a_2b_1)^2 - 4(a_1^2 + a_2^2)(a_1c_1 + a_2c_2)}.$$

Finally, after determining the elements d_1 and d_2 of the matrix $D = \begin{bmatrix} d_1 & d_2 \\ -d_2 & d_1 \end{bmatrix}$, the

matrices $X_{1,2} = -\frac{A^{-1}B}{2} \pm D$ are solutions of the matrix equation (16). On the basis of (21), it can be concluded that if

$$\begin{aligned} (a_1b_1 + a_2b_2)(a_2b_1 - a_1b_2) &= 2(a_1^2 + a_2^2)(a_1c_2 - a_2c_1) \text{ and} \\ (a_1b_1 + a_2b_2)^2 - (a_2b_1 - a_1b_2)^2 &\geq 4(a_1^2 + a_2^2)(a_1c_1 + a_2c_2), \end{aligned} \quad (24)$$

then the solutions are the bireal numbers $(x_1, 0)$ and $(x_2, 0)$. If the inequality $\geq$, in the previous condition, replaced by the inequality $<$, then the solutions are the bireal numbers (x_0, y_1) and (x_0, y_2) . Let $a_1c_2 = a_2c_1$ and $a_2b_1 = a_1b_2$. If the condition $b_2^2 \geq 4a_2c_2$ ($b_1^2 \geq 4a_1c_1$), to which the second condition in (24) is reduced, is satisfied, then the solutions of *Hamilton's* general quadratic equation are the bireal numbers $(x_1, 0)$ and $(x_2, 0)$. If $a_1c_2 = a_2c_1$ and $a_1b_1 = -a_2b_2$, and $b_1^2 \geq -4a_2c_2$ ($b_2^2 \geq -4a_1c_1$) the solutions are bireal numbers $(0, y_1)$ and $(0, y_2)$.

As emphasized above, real solutions of the equation $ax^2 + bx + c = 0$ exist if the discriminant $\Delta = b^2 - 4ac$ is nonnegative. In addition, the solutions of the quadratic equation (12), over the field of bireal numbers $\mathbb{R}^2$, which also includes *Hamilton's* couple equation (2), are in the form of bireal numbers. Accordingly, in addition to the fact that there is a complete analogy between the solution of the quadratic equation (12) and the quadratic equation with complex coefficients, the question arises: Whether it was necessary to introduce the imaginary unit i at all? *Hamilton* himself emphasized the same thing in (Hamilton, 1853), but he did not insist on it, so it was not sufficiently noticed by the rest of scientific public. More precisely, an ordinary quadratic equation $ax^2 + bx + c = 0$, defined over the field of real numbers $\mathbb{R}$, either has real solutions (if Δ is nonnegative) or has no solutions. On the other hand, *Hamilton's* couple equation, being defined over a field of bireal numbers, decomposes into a system of two nonlinear equations with two unknowns x and y . The ordered pairs of solutions of the system are bireal numbers. Consequently, the equation $x^2 = -1$ has no solution in the field of real numbers, but the solutions of *Hamilton's* couple equation $w^2 = (x, y)^2 = -1$, which decomposes into a system of two nonlinear equations: $x^2 - y^2 = -1$ and $2xy = 0$, has two real solutions $(0, 1)$ and $(0, -1)$, which belong to the field of bireal numbers.

GAUSSIAN ELIMINATION METHOD FOR SNAE

By decomposing *Hamilton's* quadratic equation (11), the following SNAE

$$\begin{aligned} a_{11}x^2 + a_{12}y^2 + 2b_1xy + c_{11}x + c_{12}y + d_1 &= 0 \\ a_{21}x^2 + a_{22}y^2 + 2b_2xy + c_{21}x + c_{22}y + d_2 &= 0. \end{aligned} \quad (25)$$

is obtained. However, *Hamilton's* quadratic equation (11) can also be written in matrix form

$$\begin{bmatrix} 1 & 1 \end{bmatrix} \left(A \begin{bmatrix} x^2 \mathbf{1} \\ y^2 \hat{\mathbf{1}} \end{bmatrix} + B \begin{bmatrix} xy \mathbf{1} \\ xy \hat{\mathbf{1}} \end{bmatrix} + C \begin{bmatrix} x \mathbf{1} \\ y \hat{\mathbf{1}} \end{bmatrix} + \begin{bmatrix} d_1 \mathbf{1} \\ d_2 \hat{\mathbf{1}} \end{bmatrix} \right) = (0, 0), \quad (26)$$

where

$$A = \begin{bmatrix} a_{11}\mathbf{1} & -a_{12}\hat{\mathbf{1}} \\ a_{21}\hat{\mathbf{1}} & a_{22}\mathbf{1} \end{bmatrix} = \begin{bmatrix} (a_{11}, 0) & (0, -a_{12}) \\ (0, a_{21}) & (a_{22}, 0) \end{bmatrix}, C = \begin{bmatrix} c_{11}\mathbf{1} & -c_{12}\hat{\mathbf{1}} \\ c_{21}\hat{\mathbf{1}} & c_{22}\mathbf{1} \end{bmatrix} = \begin{bmatrix} (c_{11}, 0) & (0, -c_{12}) \\ (0, c_{21}) & (c_{22}, 0) \end{bmatrix} \text{ and}$$

$$B = \begin{bmatrix} b_1\mathbf{1} & -b_1\hat{\mathbf{1}} \\ b_2\hat{\mathbf{1}} & b_2\mathbf{1} \end{bmatrix} = \begin{bmatrix} (b_1, 0) & (0, -b_1) \\ (0, b_2) & (b_2, 0) \end{bmatrix}.$$

$$\text{Since } \begin{bmatrix} x^2\mathbf{1} \\ y^2\hat{\mathbf{1}} \end{bmatrix} = \begin{bmatrix} x\mathbf{1} & 0\hat{\mathbf{1}} \\ 0\hat{\mathbf{1}} & y\mathbf{1} \end{bmatrix} \begin{bmatrix} x\mathbf{1} \\ y\hat{\mathbf{1}} \end{bmatrix} \text{ and } \begin{bmatrix} xy\mathbf{1} \\ yx\hat{\mathbf{1}} \end{bmatrix} = \begin{bmatrix} y\mathbf{1} & 0\hat{\mathbf{1}} \\ 0\hat{\mathbf{1}} & x\mathbf{1} \end{bmatrix} \begin{bmatrix} x\mathbf{1} \\ y\hat{\mathbf{1}} \end{bmatrix}$$

it follows that

$$\begin{aligned} & \begin{bmatrix} \mathbf{1} & \mathbf{1} \end{bmatrix} \left(A \begin{bmatrix} x^2\mathbf{1} \\ y^2\hat{\mathbf{1}} \end{bmatrix} + B \begin{bmatrix} xy\mathbf{1} \\ yx\hat{\mathbf{1}} \end{bmatrix} + C \begin{bmatrix} x\mathbf{1} \\ y\hat{\mathbf{1}} \end{bmatrix} + \begin{bmatrix} d_1\mathbf{1} \\ d_2\hat{\mathbf{1}} \end{bmatrix} \right) = \\ & = \begin{bmatrix} \mathbf{1} & \mathbf{1} \end{bmatrix} \left(\left(A \begin{bmatrix} x\mathbf{1} & 0\hat{\mathbf{1}} \\ 0\hat{\mathbf{1}} & y\mathbf{1} \end{bmatrix} + B \begin{bmatrix} y\mathbf{1} & 0\hat{\mathbf{1}} \\ 0\hat{\mathbf{1}} & x\mathbf{1} \end{bmatrix} + C \right) \begin{bmatrix} x\mathbf{1} \\ y\hat{\mathbf{1}} \end{bmatrix} + \begin{bmatrix} d_1\mathbf{1} \\ d_2\hat{\mathbf{1}} \end{bmatrix} \right) = (0, 0). \end{aligned} \quad (27)$$

$$\text{Accordingly,} \quad D \begin{bmatrix} x\mathbf{1} \\ y\hat{\mathbf{1}} \end{bmatrix} + \begin{bmatrix} d_1\mathbf{1} \\ d_2\hat{\mathbf{1}} \end{bmatrix} = \begin{bmatrix} (0, 0) \\ (0, 0) \end{bmatrix}, \quad \text{where}$$

$$D = \begin{bmatrix} (a_{11}x + b_1y + c_{11}, 0) & -(0, a_{12}y + b_1x + c_{12}) \\ (0, a_{21}x + b_2y + c_{21}) & (a_{22}y + b_2x + c_{22}, 0) \end{bmatrix}.$$

$$\text{On the assumption that the square matrix } \underline{D} = \begin{bmatrix} a_{11}x + b_1y + c_{11} & a_{12}y + b_1x + c_{12} \\ a_{21}x + b_2y + c_{21} & a_{22}y + b_2x + c_{22} \end{bmatrix},$$

such that $|D| = |\underline{D}|\mathbf{1}$, is a regular matrix, one obtains that

$$\begin{aligned} \begin{bmatrix} x\mathbf{1} \\ y\hat{\mathbf{1}} \end{bmatrix} &= -D^{-1} \begin{bmatrix} d_1\mathbf{1} \\ d_2\hat{\mathbf{1}} \end{bmatrix} = -\frac{\text{adj}D}{|D|} \begin{bmatrix} d_1\mathbf{1} \\ d_2\hat{\mathbf{1}} \end{bmatrix} = -\frac{\begin{bmatrix} (a_{22}y + b_2x + c_{22}, 0) & (0, a_{12}y + b_1x + c_{12}) \\ -(0, a_{21}x + b_2y + c_{21}) & (a_{11}x + b_1y + c_{11}, 0) \end{bmatrix}}{|\underline{D}|} \begin{bmatrix} d_1\mathbf{1} \\ d_2\hat{\mathbf{1}} \end{bmatrix} = \\ &= \frac{\begin{bmatrix} [(b_1d_2 - b_2d_1)x + (a_{12}d_2 - a_{22}d_1)y + (c_{12}d_2 - c_{22}d_1)]\mathbf{1} \\ [(a_{21}d_1 - a_{11}d_2)x - (b_1d_2 - b_2d_1)y + (c_{21}d_1 - c_{11}d_2)]\hat{\mathbf{1}} \end{bmatrix}}{(a_{11}x + b_1y + c_{11})(a_{22}y + b_2x + c_{22}) - (a_{21}x + b_2y + c_{21})(a_{12}y + b_1x + c_{12})}. \end{aligned} \quad (28)$$

On the basis of the previous equation, it follows that

$$\begin{aligned} & [|\underline{D}| - (b_1d_2 - b_2d_1)]xy = (a_{12}d_2 - a_{22}d_1)y^2 + (c_{12}d_2 - c_{22}d_1)y = \\ & = (a_{21}d_1 - a_{11}d_2)x^2 - 2(b_2d_1 - b_1d_2)xy + (c_{21}d_1 - c_{11}d_2)x, \end{aligned} \quad (29)$$

where $|\underline{D}| = (a_{11}b_2 - a_{21}b_1)x^2 + (a_{22}b_1 - a_{12}b_2)y^2 + |A|xy + (a_{11}c_{22} - a_{21}c_{12})x + (a_{22}c_{11} - a_{12}c_{21})y + |C|$, $|A| = a_{11}a_{22} - a_{12}a_{21}$ and $|C| = c_{11}c_{22} - c_{12}c_{21}$. The solutions x and y of SNAE (25) belong to the set $\{x, y, c\}$ of solutions of the following SNAE

$$\begin{aligned} [|\underline{D}| - (b_1d_2 - b_2d_1)]xy &= c \\ (a_{12}d_2 - a_{22}d_1)y^2 + (c_{12}d_2 - c_{22}d_1)y - c &= 0 \\ (a_{21}d_1 - a_{11}d_2)x^2 - [2(b_1d_2 - b_2d_1)y - (c_{21}d_1 - c_{11}d_2)]x - c &= 0, \end{aligned} \quad (30)$$

where c is an arbitrary real constant, which must satisfy two conditions. The first condition is that the discriminant Δ_y of the second equation of the system (30) is nonnegative. In that case, solving the second equation leads to the functional solution $y = f_y(c)$. The second condition is that the discriminant Δ_x of the third equation of the system (30), which includes the previous functional solution, must also be nonnegative. Under that condition and solving that equation, leads to another functional solution $x = f_x(c)$. By this elimination method of solving SNAE (25), and which is obviously similar to solving a system of linear algebraic equations by the *Gaussian* elimination method, in special cases, as in the example that follows, the solution for the unknown c , of the first equation of system (30), which includes functional solutions $f_y(c)$ and $f_x(c)$, can be obtained in a relatively simple way. However, in the general case, due to the complexity of the algebraic equation itself, in order to obtain a solution for the unknown c , computational mathematics methods would have to be used to numerically solve algebraic equations.

Example: SNAE (21): $x^2 - y^2 = d$ and $2xy = d/b$, is obtained from SNAE (25) for $a_{21} = a_{22} = b_1 = c_{11} = c_{12} = c_{21} = c_{22} = 0$, $b_2 = b \neq 0$, $a_{11} = -a_{12} = 1$ and $d_1 = d_2 = -d \neq 0$. In that case, according to (30), solutions x and y of this SNAE are solutions of SNAE: $(|\underline{D}| - bd)xy - c = 0$, $x^2 - 2byx - c/d = 0$ and $y^2 - c/d = 0$. From the last equation of this system it follows that $y = \pm\sqrt{c/d}$. If this value for y is included in the second equation of the system, the value for x is obtain, so that $x = (b \pm \sqrt{1+b^2})y$. On the other hand,

$$|\underline{D}| = b(x^2 + y^2) = \frac{bc}{d}[1 + (b \pm \sqrt{1+b^2})^2] = \frac{bc}{d}(1 + \frac{b \pm \sqrt{1+b^2}}{-b \pm \sqrt{1+b^2}}) = \frac{2bc}{d} \frac{\pm\sqrt{1+b^2}}{-b \pm \sqrt{1+b^2}}.$$

According to the first equation of the sistem,

$$\frac{|\underline{D}|}{d} = \frac{1}{b \pm \sqrt{1+b^2}} + b = \pm\sqrt{1+b^2},$$

since $xy = c(b \pm \sqrt{1+b^2})/d$. Therefore, $2bc = d^2(-b \pm \sqrt{1+b^2}) \geq 0$, so that

$$y = \pm\sqrt{\frac{d}{2b}(-b \pm \sqrt{1+b^2})} \text{ and } x = (b \pm \sqrt{1+b^2})y = \pm\sqrt{\frac{d}{2b}}(b \pm \sqrt{1+b^2}).$$

CONCLUSIONS

The main purpose of this manuscript is to reaffirm *Hamilton's* idea to make the solutions of polynomial equations completely real and autonomous from complex numbers (Hamilton, 1853). Namely, by defining couple (bireal) numbers, *Hamilton* reduces the system of two algebraic equations with two unknowns to one couple equation, the solutions of which are ordered pairs of real numbers. In addition, the so called matrix method for solving *Hamilton's* quadratic equations

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is presented, which in the general case is somewhat analogous to the *Gaussian* elimination method. Finally, it was presented that *Hamilton's* linear differential equation, with a system of two characteristic algebraic equations, also has solutions in the form of an ordered pair of two real numbers. Accordingly, we can draw the conclusion that bireal numbers, as solutions of polynomial equations, are more suitable and mathematically correct than complex numbers.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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ULOGA KANCELARIJE VISOKOG PREDSTAVNIKA U POSTDEJTONSKOJ BOSNI I HERCEGOVINI (1997-2009)

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APSTRAKT

Aneks X Dejtonskog mirovnog definisao je nadležnosti Kancelarije Visokog predstavnika. Nakon prvih posleratnih izbora održanih 1996. godine, međunarodni akteri su videli da političke elite nemaju interes za uspostavljanje institucija na nivou Bosne i Hercegovine, koje su bile neophodne za funkcionisanje države. U decembru 1997. godine u Bonu je održana konferencija na kojoj su proširene nadležnosti visokog predstavnika.

Glavno istraživačko pitanje u ovom radu je: Kakva je uloga OHR-a u procesu izgradnje institucija u Bosni i Hercegovini. Koristićemo uporednu metodu kako bismo uporedili dinamiku korišćenja bonških ovlašćenja u različitim periodima, kao i ulogu visokog predstavnika u političkim procesima. Pored uporedne metode, koristićemo i deskriptivnu metodu i analizu sadržaja kako bismo objedinili i bolje protumačili prethodne analize i radove koji se bave ovom temom.

Relevantnost teme proizilazi iz činjenice da se ove godine obeležava 30. godišnjica Dejtonskog mirovnog sporazuma, a Bosna i Hercegovina se nalazi u najvećoj postdejtonskoj krizi.

Ključne riječi: Dejtonski mirovni sporazum, Kancelarija Visokog predstavnika, Bosna i Hercegovina, izgradnja države.

UVOD

Opšti okvirni sporazum za mir u Bosni i Hercegovini poznatiji pod nazivom Dejtonski mirovni sporazum prafiran je 21. novembra 1995. godine u vojnoj bazi Rajt-Peterson u gradu Dejtonu, dok je formalno potpisan 14. decembra 1995. godine u Parizu. Dejtonski mirovni sporazum (u nastavku DMS) okončao je troipogodišnji rat, uspostavio ustavno-politički sistem i omogućio integritet države. DMS sastoji se od jedanaest aneksa od kojih Aneks IV je Ustav Bosne i Hercegovine, a Aneks X je Civilna implementacija mira gdje je regulisano pitanje Kancelarije Visokog predstavnika¹. Autorka Simić navodi kako je DMS-om uspostavljena izvjesna vrsta protektorata posredstvom Sporazuma o vojnim aspektima mirovnog rješenja i Sporazuma o civilnom sprovođenju mirovnog rješenja (Aneksa 1A i Aneksa 10), odnosno angažovanjem vojnih snaga međunarodne zajednice, NATO-a, i visokog predstavnika koji je istovremeno vrhovni autoritet za tumačenje i sporovođnje Dejtonskog mirovnog sporazuma (Simić, 2016, 72). Uloga visokog predstavnika u periodu od 1995. do 1997. godine bila je da olakša napore političkih elita u primjeni mirovnog sporazuma. U decembru 1997. godine u Bonu održana je konferencija posvećena sprovođenju mira u Bosni i Hercegovini gdje su nadležnosti visokog predstavnika proširene. Visoki predstavnik dobio je nadležnost da može da smijeni javne službenike ili funkcionere koji opstruišu implementaciju mirovnog sporazuma ili za koje visoki predstavnik smatra da narušavaju pravne obaveze koje su uspostavljene mirovnim sporazumom. Uloga visokog

¹Ostali aneksi sporazuma su: Aneks I-A: Vojni aspekti mirovnog sporazuma; Aneks I-B: Regionalna stabilizacija; Aneks II: Granice između entiteta; Aneks III: Izbori; Aneks V: Arbitraža; Aneks VI: Ljudska prava; Aneks VII: Izbjeglice i raseljena lica; Aneks VIII: Komisija za zaštitu nacionalnih spomenika; Aneks IX: Javne korporacije Bosne i Hercegovine; Aneks XI: Međunarodne policijske snage (<https://ndcsarajevo.org/Dokumenti/Dejtonski-mirovni-sporazum.pdf>).

predstavnika se transformisala iz posmatračke u aktivnog političkog aktera u izgradnji države i jačanju institucija na nivou Bosne i Hercegovine.

TEORIJSKI OKVIR

Oružani sukobi koji su se dešavali nakon završetka Hladnog rata okončavani su potpisivanjem mirovnih sporazuma. Bel u svom radu posvećenom mirovnim sporazumima navodi i četiri karakteristike mirovnih sporazuma:

- Sukobi nakon završetka Hladnog rata najčešće su se dešavali unutar državnih granica, a privlačili su pažnju međunarodnih aktera;
- Pojavio se zajednički pristup rješavanju sukoba koji je podrazumijevao direktne pregovore između zaraćenih strana u kojoj su svi učesnici u sukobu tretirani kao jednaki;
- Osim okončanja oružanih sukoba mirovnim sporazumima predviđeni su novi politički i ustavni aranžmani za držanje i vršenje vlasti nakon okončanja sukoba;
- Postignuti sporazumi bili su formalno dokumentovani u pisanom obliku koji su potpisivale zaraćene strane uz prisustvo međunarodnih aktera (Bell, 2006, 373-374).

Ustavni i politički aranžmani proistekli iz mirovnih sporazuma predviđaju složene institucionalne aranžmane koji u sebi sadrže elemente konsocijacijske demokratije¹. Teoretičari su saglasni da je u teoriji Bosna i Hercegovina konsocijacijska demokratija, ali da u praksi ipak to nije. Kasapović smatra da je za postojanje konsocijacijske demokratije potrebno da etničke grupe žive jedne sa drugima, a ne jedne pored drugih. Dodatni argument je da u Bosni i Hercegovini nikada nije postojao konsenzus o državnoj zajednici. Srpska i hrvatska etnička zajednica dale su minimalnu saglasnost, dok je za bošnjačku zajednicu dejtonski model samo prelazno rješenje u izgradnji građanske države bez teritorijalne podjele kakva je danas (Kasapović, 2017, 177). Prema ocjeni Nermine Mujagić u Bosni i Hercegovini postoje elementi federalizma, ali to su elementi etničkog federalizma koji je upitan kao model za razvoj prosperitetne Bosne i Hercegovine (Mujagić, 2010, 94). Jedan od elemenata etničkog federalizma ogleda se u političkom smislu zastupljenosti samo konstitutivnih naroda dok građani koji se ne svrstavaju u jednu od nacionalnih grupa nemaju pasivno biračko pravo. Pojam građanina Bosne i Hercegovine nema faktičku vrijednost i zamijenjen je etnikumom. U prvoj deceniji nakon potpisivanja DMS-a Bosna i Hercegovina je imala uspjehe u procesu demokratizacije i uspostavi funkcionalne države, međutim u drugoj deceniji imamo obrnut trend. Merdžanović objašnjava da razlozi leže u tome što u prvoj deceniji imamo međunarodni intervencionizam u Bosni i Hercegovini. Visoki predstavnik kao predstavnik međunarodne zajednice ublažavao je kroz svoje odluke disfunkcionalnost sistema, međutim nakon prve decenije imamo povlačenje u smislu intervencionizma i tada su na površinu isplivali problemi i nastaju paralize sistema. Iz tog razloga imamo sve češće kritike na račun konsocijacijskog modela. Međutim, takav pristup zanemaruje ključni kontinuitet između dve dekade razvoja. Naime, dugotrajna spoljna intervencija nije samo ublažavala negativne efekte sistema, već je suštinski preoblikovala njegove unutrašnje odnose i obrascе političkog ponašanja. Time je konstruisan specifičan oblik konsocijacijske demokratije – nametnutu konsocijaciju – koja se odlikuje zavisnošću od spoljnog autoriteta i oslabljenim kapacitetom za organski institucionalni razvoj (Merdžanović, 2016, 3). Radovi koji se bave DMS-om u fokus stavljaju posebne aspekte sporazuma. Najčešće teme kojima su se teoretičari bavili su Ustav Bosne i Hercegovine i Civilna implementacija mira koje su usko povezane iako su odvojene u dva posebna aneksa. Uporedna

¹ Pojam konsocijacijska demokratija formulisao je Johan Althusius. a od njega ga je preuzeo Arent Lajphart koji je naveo četiri ključna elementa koje svaka konsocijacijska demokratija ima: 1. Velika koalicija političkih partija svih značajnih segmenata pluralnog društva; 2. Međusobni veto ili načelo “većine istomišljenika” koje služi kao dodatna zaštita vitalnih manjinskih interesa; 3. Proporcionalnost kao osnovno mjerilo pri određivanju političke zastupljenosti kod imenovanja državnih činovnika i raspodjeli javnih fondova; 4. Visok stepen samostalnosti svakog segmenta u odlučivanju o unutrašnjim pitanjima; pogledati Lajphart: “Demokratija u pluralnim društvima”, 1977. str. 32

analiza donosi nam uvid u upotrebu Bonskih ovlaštenja, koji su ključni mehanizam Kancelarije visokog predstavnika. Visoki predstavnici od decembra 1997. godine do danas imali su ista ovlaštenja, međutim upotreba Bonskih ovlaštenja zavisila je prvenstveno od podrške koju im je pružala međunarodna zajednica. U situacijama kada postoji jedinstven stav međunarodne zajednice primjećena je i aktivnija uloga visokog predstavnika (Beglerović, 2022, 406). Pored uporedne analize značajna je i analiza sadržaja radova, ali i akata koji se odnose na ulogu Kancelarije visokog predstavnika.

ULOGA VISOKOG PREDSTAVNIKA

Od potpisivanja DMS-a u Bosni i Hercegovini visoki predstavnici bili su: Karl Bilt, Karlos Vestendorp, Wolfgang Petrič, Pedi Ešdaun, Kristijan Švarc-Šiling, Miroslav Lajčak, Valentin Incko i Kristijan Šmit. Imenovanje Kristijana Šmita i danas je tema u domaćoj političkoj i stručnoj javnosti. U svom radu posvećenom prirodi akata visokog predstavnika, Vlaški i Romić pozivaju se na član I.2 Aneksa X kojim je predviđeno da visoki predstavnik bude imenovan u skladu sa relevantnom rezolucijom Savjeta bezbjednosti Ujedinjenih nacija. U slučaju imenovanja Kristijana Šmita, Savjet bezbjednosti se nije izjašnjavao, odnosno nije donijeta relevantna rezolucija. Iz tog razloga legitimitet i legalitet Kristijana Šmita se osporava u Republici Srpskoj. U pismu iz 2023. godine, koje je član Predsjedništva iz Republike Srpske uputila generalnom sekretaru Ujedinjenih nacija, a u vezi sa imenovanjem Kristijana Šmita za visokog predstavnika u Bosni i Hercegovini. Generalni sekretar Ujedinjenih nacija navodi da na osnovu teksta Aneksa X, jasno je da Savjet bezbjednosti UN-a nije nadležno za imenovanje visokih predstavnika. Iako imenovanje visokog predstavnika mora biti usklađeno sa odgovarajućim rezolucijama Savjeta bezbjednosti UN-a, praksa Savjeta za provođenje mira jasno ukazuje da je imenovanje visokog predstavnika u nadležnosti upravnog odbora Savjeta za provođenje mira. Ova praksa je utemeljena rezolucijom Savjeta bezbjednosti UN-a br. 1031 iz 1995. godine. Dalje u odgovoru navodi se da rezolucije Savjeta bezbjednosti UN-a nisu pravno nužne za imenovanje visokog predstavnika, budući da je praksa pokazala da je imenovanje već postalo efektivno prije nego što je Savjet bezbjednosti izreklo formalnu saglasnost. Izražavanje podrške u rezolucijama nije zakonski obavezno za početak funkcije novog visokog predstavnika. Važno je napomenuti da je izostanak izričitog pomena imenovanja visokog predstavnika u rezolucijama Savjeta bezbjednosti UN-a presedan koji nije nov. Naime, nakon što je upravni odbor Savjeta za provođenje mira 15. decembra 2005. godine imenovao Kristijana Švarc-Šilinga za visokog predstavnika, Savjet bezbjednosti UN-a nije izričito spomenulo to imenovanje u svojim rezolucijama. Ovaj pristup implicira da izričita podrška Savjeta bezbjednosti UN-a nije pravno obavezna za stupanje na snagu odluke upravnog odbora Savjeta za provođenje mira (Imenovanje visokih predstavnika, 2023).

Visoki predstavnik nije eksplicitno intervenisao u tekst Ustava Bosne i Hercegovine, ali ga je mijenjao, dopunjavao ili razrađivao donošenjem određenih zakona. Tim zakonima dopunjavao je ustavnu materiju, ili ju je regulisao drugačije nego što je to učinio ustavotvorac, koji je mnoga pitanja u Dejtonskom ustavu ostavio nedorečenim (Banović, Gavrić, 2010, 67). Visoki predstavnik je svoju ulogu ostvarivao donošenjem ustavnih amandmana na entitetske ustave, donošenjem zakonskih i podzakonskih akata, tumačenja propisa, promocijom reformi, mjera i aktivnosti koje su podrazumijevale nove zakone i stvaranje novih institucija na nivou Bosne i Hercegovine, kao i odlukama o smjenjivanju lica, zabrani rada, kandidovanja i političkog angažovanja tih lica (Karan; 2015, 70). U analizi akata koje je donosio visoki predstavnik Karan razlikuje tri vrste akata: akti u formi zakona, akti u formi odluke kojom se proglašava zakon i odluke koje imaju karakter pojedinačnog akta (smjene ličnosti). Analizom zvanične stranice Kancelarije visokog predstavnika utvrđeno je da u periodu od 1997. do 2009. godine broj odluka visokog predstavnika je preko 800 odluka, od čega je preko 300 odluka u formi zakona. Knaus i Martin navode da je u periodu od 2001. do 2002. godine visoki predstavnik nametnuo 207 odluka, od čega je 53 odluke donio Petrič, a Ešdaun 153 odluke (Knaus, & Martin, 2003, 68). U periodu od 1998. do 2008. godine, Parlamentarna skupština Bosne i Hercegovine usvojila je ukupno 391 zakon, od kojih je visoki predstavnik nametnuo 112, a koji su kasnije usvojeni u Parlamentarnoj skupštini. Neki od zakona

koje je nametnuo visoki predstavnik bili su: Zakon o Sudu Bosne i Hercegovine, Zakon o Tužilaštvu Bosne i Hercegovine, Zakon o zastavi, Zakon o državljanstvu i drugi.

U članu 1.2 Ustava Bosna i Hercegovina definisana je kao demokratska država koja funkcioniše u skladu sa zakonom i na osnovu slobodnih i demokratskih izbora. Član 3.1 predvidio je nadležnosti institucija Bosne i Hercegovine², dok sve nadležnosti koje nisu eksplicitno dodjeljene institucijama Bosne i Hercegovine pripadaju entitetima. Dodatne nadležnosti institucija Bosne i Hercegovine predviđene su u članu 3.5 gdje se navodi da će institucije Bosne i Hercegovine preuzeti nadležnosti u kojima se o tome postigne saglasnost entiteta; stvarima koje su predviđene u Aneksima 5 - 8 Opšteg okvirnog sporazuma; ili koje su potrebne za očuvanje suvereniteta, teritorijalnog integriteta, političke nezavisnosti i međunarodnog subjektiviteta Bosne i Hercegovine, u skladu sa podjelom nadležnosti među institucijama Bosne i Hercegovine. Pored termina preuzimanje nadležnosti koristi se i termin prenos nadležnosti koji se odnosi na sporazum između entiteta o prenosu nadležnosti sa nivoa entiteta na nivo Bosne i Hercegovine.

Odlukom visokog predstavnika Karlosa Vestendorpa uspostavljen je Sud Bosne i Hercegovine, međutim zakon u istoj formi usvojila je Parlamentarna skupština Bosne i Hercegovine. Zakon o Sudu više puta je u redovnoj parlamentarnoj proceduri pretrpio izmjene i dopune. U samom tekstu Ustava predviđen je Ustavni sud Bosne i Hercegovine, dok druge institucije nisu upisane u samom tekstu Ustava zbog čega se često njihov legitimitet i legalitet osporava. Osporavanje legitimiteta pravosudnih institucija poteklo je iz sfere političkog, a kasnije se, u manjoj mjeri prelilo i na sferu teorijskog. Postoje dva suprotna tumačenja legitimnosti Suda Bosne i Hercegovine, ali i drugih pravosudnih institucija. Prema prvom tumačenju osnivanje pravosudnih institucija na nivou Bosne i Hercegovine je neustavno jer u samom tekstu Ustava ne navodi se da institucijama Bosne i Hercegovine pripada nadležnost u vršenju sudske vlasti. Po drugom tumačenju, iako Ustav nije izričito predvidio formiranje Suda, mogućnost proističe iz člana 1.2 i člana 3.5 Ustava Bosne i Hercegovine. Iz člana 3.5 proizilazi da Ustav nije precizirao koje institucije treba da budu osnovane, ali Parlamentarna skupština Bosne i Hercegovine može osnovati Sud Bosne i Hercegovine ako ocijeni da je neophodno za vršenje državnih nadležnosti. Osnivanjem Suda Bosne i Hercegovine ne dovodi se u pitanje dejtonska struktura Bosne i Hercegovine, niti izvršena podjela nadležnosti između države i entiteta, jer se ne zadire u ustavne nadležnosti entiteta, ne mijenjaju se njihovi sudski sistemi, niti se državi omogućava da interveniše urješavanje sporova koji proističu iz primjene entitetskog prava. Sud Bosne i Hercegovine nije hijerarhijski nadređen entitetskim sudovima, nego postoji pored njih. Iako se osnivanjem Suda Bosne i Hercegovine mijenja struktura pravosudnog sistema, to se ne čini na štetu autonomije entiteta i funkcionisanja njihovih sudskih sistema (Marković, 2012, 48).

Visoki predstavnik osim što je donosio odluke u formi zakona, Bosna ovlaštenja koristio je i u svrhu smjenjivanje javnih funkcionera. Visoki predstavnik u martu 1999. godine donio je odluku kojom je smijenjen tadašnji predsjednik Republike Srpske Nikola Poplašen. U obrazloženju odluke navodi se da je blokirao konstituisanje vlasti u ovom entitetu i da nije poštovao volju građana (Office of high representative, 1999). Osim smjene Nikole Poplašena, u martu 2004. godine u jednom danu smijenjeno je 59 najviših funkcionera Srpske demokratske stranke (Office of high representative, 2004). Razlozi za smjene javnih funkcionera bili su različiti, ali najčešće se u obrazloženju odluka navodi da su činili mrežu pomagača u skrivanju optuženih za ratne zločine pred domaćim sudovima i Međunarodnim krivičnim sudom za bivšu Jugoslaviju. Pored nametanja odluka u formi zakona, visoki predstavnik bio je i medijator u uspostavljanju institucija na nivou Bosne i Hercegovine. Visoki predstavnik donio je uputstvo koje je uputio entitetskim vlastima u

² Nadležnosti institucija Bosne i Hercegovine po članu 3.1. su: spoljna politika; spoljnotrgovinska politika; carinska politika; monetarna politika kao što je predviđeno članom 7; finansiranje institucija i međunarodnih obaveza Bosne i Hercegovine; politika i regulisanje pitanja imigracija, izbjeglica i azila; provođenje međunarodnih i međuentitetskih krivičnopravnih propisa, uključujući i odnose sa Interpolom; uspostavljanje i funkcionisanje zajedničkih i međunarodnih komunikacijskih sredstava; regulisanje međuentitetskog transporta; kontrola vazdušnog saobraćaja (Ustav Bosne i Hercegovine, 1995)

cilju otpočinjanja pregovora oko prenosa nadležnosti u oblasti pravosuđa na nivo Bosne i Hercegovine u cilju formiranja Visokog sudskog i tužilačkog savjeta Bosne i Hercegovine. Kako navode Akšamija i Jahić, u slučaju osnivanja VSTS-a izvršen je prenos nadležnosti, ali za razliku od prenosa nadležnosti iz oblasti odbrane u slučaju VSTS-a osnov proizilazi iz člana 3.5 Ustava. Ovaj slučaj je specifičan jer je zahtijevao uključivanje države u sporazum, s obzirom da je VSTS objedinjavao prethodne odvojene institucije, što je impliciralo potrebu za državnom koordinacijom. Procedura davanja saglasnosti na ove prenose varirala je među entitetima – Federacija BiH ju je obezbjeđivala putem oba doma parlamenta, dok je Republika Srpska koristila odluke Narodne skupštine, bez potrebe za ustavnim amandmanima. U oblasti odbrane, međutim, prenos nadležnosti je naknadno potvrđen i formalizovan izmjenama entitetskih ustava³. Česta upotreba bonških ovlaštenja dovela je do toga da su se političke elite postale nevoljne za postizanjem kompromisa jer su smatrali da će u slučaju nepostizanja dogovora visoki predstavnik iskoristiti bonška ovlaštenja. Merdžanović i Bursać, u svojim radovima navode da je česta upotreba bonških ovlaštenja dovela je da Visoki predstavnik postane veto igrač u političkom sistemu Bosne i Hercegovine⁴.

Dodatni problem u donošenju odluka visokog predstavnika je što ne postoji adekvatna pravna zaštita od istih. U zahtjevu za ocjenu ustavnosti Zakona o državnoj graničnoj službi koji je svojom odlukom donio visoki predstavnik 13. januara 2000. godine u kojem se navodi da visoki predstavnik nema normativnih ovlaštenja da nametne zakon u slučaju da ga ne izglasa Parlamentarna skupština Bosne i Hercegovine jer mu se ni Dejtonski mirovnim sporazumom, a ni Bonskom deklaracijom ne dodjeljuju normativna ovlaštenja. U obrazloženju odluke, Ustavni sud navodi sljedeće: “Zakon o državnoj graničnoj službi Bosne i Hercegovine je “nametnuo” visoki predstavnik međunarodne zajednice u Bosni i Hercegovini, nakon što Parlamentarna skupština Bosne i Hercegovine nije usvojila Nacrt zakona koji je predložilo Predsjedništvo Bosne i Hercegovine. U konkretnom slučaju visoki predstavnik - čija ovlaštenja koje proizilaze iz Aneksa X Opšteg okvirnog sporazuma za mir u Bosni i Hercegovini, relevantnih rezolucija Vijeća sigurnosti Ujedinjenih nacija i Bonske deklaracije, nisu podložne kontroli Ustavnog suda, kao ni vršenje tih ovlasti - je intervenisao u pravni sistem Bosne i Hercegovine, supstituirajući domaće vlasti. U tom pogledu on je, stoga, djelovao kao vlast Bosne i Hercegovine, a zakon, koji je on donio, je prirode domaćeg zakona te se mora smatrati zakonom Bosne i Hercegovine, čija je saglasnost sa Ustavom Bosne i Hercegovine podložna kontroli Ustavnog suda, na osnovu člana VI.3.(a) Ustava Bosne i Hercegovine.” (U 9/00 BiH Zakon o državnoj graničnoj službi „Sl. gl. BiH“ broj 01/02). Navedena odluka Ustavnog suda dobar je primjer o nepostojanju adekvatne pravne zaštite od odluka donesenih od strane visokog predstavnika što kritičari često navode kao jedan od najvećih problema u procesu narušavanja unutrašnjeg suvereniteta Bosne i Hercegovine ali i samovolje ove institucije jer ne postoje adekvatni mehanizmi kojim bi se odluka poništila.

KRITIKE BONŠKIH OVLAŠTENJA

Problemizovanje upotrebe bonških ovlaštenja nije izostalo i u naučnoj, ali ni u političkoj sferi. Knaus i Martin u svom radu posvećenom Bosni i Hercegovini navode da su se visoki predstavnici ponašali kao neokolonijalni upravnici. Nakon izbora 2000. godine vlast je konstituisana od strane “nenaciolanih stranaka” i tada se činilo da će intervencionizam međunarodne zajednice biti sveden na minimum, ali to nije bio slučaj. Savez za promjene uživao je raznovrsne oblike podrške međunarodnih aktera – od suptilnih kampanja poput OSCE-ovih plakata

³Neven Akšamija, Kemal Jahić: “Ustav Bosne i Hercegovine 1995. i 2022. godine”, Pravna misao (Sarajevo), br.11-12, 2022; str.12

⁴Pogledati: Adis Merdžanović: “Imposed consociationalism’: external intervention and power sharing in Bosnia and Herzegovina”, Peacebuilding, 2016, str. 9; Dejan Bursać: “Dejtonski veto igrač u političkom sistemu Bosne i Hercegovine” u Dvadeset godina od Dejtonskog mirovnog sporazuma - trajni mir ili trajni izazovi? Zbornik radova, Univerzitet u Beogradu - Fakultet političkih nauka, 2016, str. 96

s porukom "Glasaj za promjene", do eksplicitnih političkih pritisaka, uključujući izjavu ambasadora Ričarda Holbruka da će Sjedinjene Američke Države obustaviti svu pomoć Republici Srpskoj ukoliko Srpska demokratska stranka bude uključena u buduću vlast. Uprkos očekivanjima o političkoj autonomiji novoizabrane vlasti, Visoki predstavnik je već dan nakon izbora nametnuo deset zakona, koji su se odnosili na različite sfere, uključujući pravosuđe i sistem mjera i vaga. Novoizabranim zvaničnicima uručeni su spiskovi dodatnih zakona uz instrukcije da ih usvoje u roku od stotinu dana. Ova praksa izazvala je vrlo ograničenu javnu kritiku, a pojedini mediji čak su podržali ovakvo ponašanje međunarodne administracije⁵. Kritike na račun upotrebe bonskih ovlaštenja imali su i Vijeća Evrope i Venecijanska komisija. Ovlaštenja se mogu klasifikovati kao ovlaštenja u hitnoj situaciji. Po samoj svojoj prirodi, takva ovlaštenja u hitnoj situaciji moraju prestati kada nestane hitna situacija koja je izvorno opravdavala njihovo korištenje (Venecijanska komisija; 2005, t.87). Ovakva praksa ne odgovara demokratskim principima, kad se koristi bez zakonskog postupka i mogućnosti pravosudne kontrole. Vremenom njeno opravdanje postaje upitnije. Komisija, shodno tome, poziva na progresivno i postepeno isključivanje ovih ovlaštenja i na uspostavu savjetodavnog panela nezavisnih pravnika za odluke koje se direktno tiču prava pojedinaca, do kraja takve prakse (Venecijanska komisija, 2005, t.100). Nakon imenovanja Kristijana Šmita za visokog predstavnika u Bosni i Hercegovini počinje i u naučnim krugovima u Republici Srpskoj da se govori o nelegitimnosti i problematici upotrebe bonskih ovlaštenja. U svom radu Vlaški i Romić iznose niz zamjerki na račun Kancelarije visokog predstavnika i bonskih ovlaštenja. Upotreba tzv. bonskih ovlaštenja predstavlja ozbiljno narušavanje suvereniteta Bosne i Hercegovine, čime se dolazi u koliziju s osnovnim načelima međunarodnog prava, naročito čl. 2(7) i čl. 78 Povelje Ujedinjenih nacija, koji garantuju suverenu jednakost i zabranu vanjskog miješanja u unutrašnje poslove država članica. U tom kontekstu, pozivanje na politički konsenzus Savjeta za implementaciju mira kao izvor legitimiteta za donošenje obavezujućih odluka bez saglasnosti domaćih vlasti, autor označava kao nelegalnu praksu bez pravnog uporišta. Bonska ovlaštenja se ocjenjuju kao instrumenti političke, a ne pravne prirode, ukorijenjeni u posthladnoratovskoj ideologiji zapadne intervencije, u kojoj dominira dvostruki standard međunarodnog djelovanja. Ovaj model je, kako autor naglašava, zasnovan na "neokolonijalnim" principima, gdje se politička volja međunarodne zajednice postavlja iznad pravne volje domaćih institucija (Vlaški i Romić, 2023, 107-108).

ZAKLJUČCI

U periodu od 1997. do 2009. godine Kancelarija Visokog predstavnika imala je aktivnu ulogu u izgradnji institucija na nivou Bosne i Hercegovine. Intervencije visokog predstavnika, poput nametanja zakona, smjena javnih funkcionera i posrednika u pregovorima oko prenosa nadležnosti etablirali su ulogu visokog predstavnika kao veto igrača u političkom sistemu Bosne i Hercegovine. Intervencije visokog predstavnika za cilj su imali prevazilaženje blokada i osiguranje funkcionisanja institucija Bosne i Hercegovine, one su u značajnoj mjeri narušile demokratski legitimitet i suverenitet zemlje, što je posebno bilo predmet kritike u kasnijim fazama. Korišćenjem bonskih ovlaštenja, Visoki predstavnici doprinijeli su stvaranju ključnih državnih tijela poput Suda BiH i Visokog sudskog i tužilačkog savjeta, ali su time istovremeno uticali na izgradnju specifičnog modela tzv. *nametnute konsocijacije*, zavisne od međunarodne intervencije. Česta i intenzivna upotreba ovih ovlaštenja obeshrabrila je lokalne političke aktere da preuzmu odgovornost za postizanje kompromisa, oslanjajući se na stranu arbitražu. Iako su pojedine odluke visokih predstavnika bile od suštinskog značaja za funkcionisanje države, odsustvo pravnih mehanizama kontrole i nedostatak odgovornosti doveli su do erozije povjerenja u institucije i potencijalno učvrstili postojeće etnonacionalne podjele. Stoga, budućnost Bosne i Hercegovine kao funkcionalne i demokratske države zahtijeva redefinisanje uloge međunarodne zajednice, smanjenje vanjskog tutorstva, te jačanje unutrašnjih kapaciteta i političkog dijaloga između domaćih aktera. Kancelarija Visokog predstavnika, iako presudna u ranim fazama tranzicije, treba

⁵ Gerald Knaus, Felix Martin: "Lessons from Bosnia and Herzegovina: "Travails of the European Raj", *Journal of Democracy*, Vol.14, No.3 (2003), str. 67

Lozo, N. (2025). Uloga kancelarije visokog predstavnika u postdejtonskoj Bosni i Hercegovini (1997-2009). *STED Conference 14*(2), 469-476.

da svoj mandat završi postepenim prenošenjem odgovornosti domaćim institucijama, uz osiguranje dugoročne stabilnosti i pravne države.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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THE ROLE OF OFFICE OF THE HIGH REPRESENTATIVE IN POST-DAYTON BOSNIA AND HERZEGOVINA (1997-2009)

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ABSTRACT

Annex X of Dayton Peace Agreement defines the competences of the OHR. After the first post-war elections held in 1996, international actors saw that the political elites had no interest in establishing institutions at the level of Bosnia and Herzegovina, which were necessary for the functioning of the state. In December 1997, a conference was held in Bonn where the competences of the High Representative were expanded. The main research question in this paper is: What is the role of OHR in the process of building institutions in Bosnia and Herzegovina. We will use the comparative method in order to compare the dynamics of the use of Bonn powers in different periods, as well as the role of the High Representative in political processes. In addition to the comparative method, we will also use the descriptive method and content analysis in order to unify and better interpret the previous analyzes and works dealing with this topic. The relevance of the topic stems from the fact that this year marks the 30th anniversary of the Dayton Peace Agreement, and Bosnia and Herzegovina is in the biggest post-Dayton crisis.

Keywords: Dayton Peace Agreement, Office of the High Representative, Bosnia and Herzegovina, state-building.

THE LANDSCAPE OF CONTEMPORARY ARCHITECTURE IN THE REPUBLIC OF SRPSKA, 1997–2023

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ABSTRACT

Understanding the development of contemporary architecture requires observation within a specific territory, time frame, and social context. In conditions marked by a lack of architectural culture and systematic documentation, this process becomes a challenge that calls for a dedicated research effort. This paper presents the landscape of contemporary architecture in the Republic of Srpska from 1997 to 2023, based on research conducted for the exhibition *25 Years of (the School of) Architecture in the Republic of Srpska*. Through the analysis of everyday architectural experiences, spatial perception shaped by movement through the territory, and a curatorial approach, this paper explores the complexity involved in researching and evaluating architectural production. It identifies and critically presents the most significant examples, highlighting their typological diversity, territorial distribution, and temporal dynamics, as a reflection of a society in post-transitional transformation. The research findings aim to contribute to the improvement of architectural education and the enhancement of spatial culture in the local, regional, and broader context.

Keywords: school of architecture, architectural scene, architectural exhibition, social role of architecture,

INTRODUCTION

Contemporary architecture represents a dynamic field of ideas, styles, and tendencies, yet it is always deeply rooted in the specific cultural, social, and material conditions of its context (Hays, 1998). As such, architecture possesses a transformative potential—it not only shapes physical space but also influences social relations, cultural identity, and urban development (Sassen, 2001). Therefore, any analysis must be framed within clearly defined temporal, territorial, and social coordinates. In 2023, the Faculty of Architecture, Civil Engineering and Geodesy at the University of Banja Luka marked 25 years since the establishment of its Architecture program—an occasion to reflect on the development of contemporary architecture in Republika Srpska. The exhibition *A.25 – 25 Years of (the School of) Architecture in Republika Srpska* was conceived as a platform for documenting and critically engaging with architectural production during this period. The exhibition focused on local specificities and their influence on architectural design, as well as the role of architecture in reflecting and shaping spatial and societal transformations (Kester, 2002). By presenting a selection of the most significant built works, it provided insight into the complexity of architectural development—its discontinuities, continuities, and dilemmas—and served as a basis for defining quality criteria and positioning the local architectural scene within a broader European context (Nesbitt, 1996). In a time of increasingly complex challenges, rethinking the role of architecture in shaping society and spatial culture becomes crucial for understanding the future.

Exhibiting Architecture

“What frustrates in architectural exhibitions is the fact that they relate either to the past or to some hypothetical future—always in a mediated form: codified and irreversibly distant. From project to realization, the path is long and arduous, often unattainable. Space and its representation are conveyed through signs that are difficult to read” (Siza, 2006). In his essay *Projects in the Exhibition*, renowned Portuguese architect Álvaro Siza highlights the limitations of exhibitions in capturing the essence of architecture as a process of creation. While his criticism holds some truth, architectural exhibitions nonetheless fulfill an important role.

Exhibiting architectural works is vital for promoting and transferring knowledge in the field. Architecture should be seen as an active agent of culture and communication. From this perspective, it is not only the final physical form that matters, but also the dialogue between concept and culture, creator and audience. Architecture becomes a site of complex communication (Milić Aleksić, 2022), enabling architects to share their ideas, experiences, and interpretations with professionals and the wider public. Many theorists have explored the significance of exhibiting architecture. Le Corbusier, a pioneer of modernist architecture, played a key role in promoting his vision through exhibitions, notably the 1925 *Exposition des Arts Décoratifs* in Paris, later discussed in his book *Toward an Architecture* (1977). Walter Gropius, founder of the Bauhaus school, also curated numerous exhibitions that disseminated the Bauhaus aesthetic globally. In *The New Architecture and the Bauhaus* (1971), he reflects on the exhibition as a medium for spreading architectural ideologies.

Bruno Zevi, perhaps the most comprehensive theorist on architectural interpretation, identified nine modes of understanding architecture—emphasizing that architecture should be interpreted not only through its physical attributes, but through all available direct and indirect information. In doing so, he also emphasized the political dimension of architecture, claiming that “architecture represents the visual dimension of history” (Zevi, 1966). Peter Zumthor’s reflections remain highly relevant in the contemporary context. In *Thinking Architecture* (2006), he insists that architecture must respond to its inherent questions—independent of societal distractions. It is not a symbol or vehicle for external values, but a discipline with its own language. This language is not tied to a particular style, but to specific uses, places, and communities. Although exhibitions, as Siza argues, cannot fully replicate the spatial and experiential essence of architecture, their value lies not in faithful representation, but in the potential for communication, interpretation, and dialogue. They act as a cultural and social medium, translating architecture into a broader discourse and revealing meanings formed between idea, form, and audience. Through drawings, models, texts, and interpretations, exhibitions offer a view of architecture as a dynamic process, a cultural act, and a space open to critical reflection. Their aim is not to replace the experience of space, but to initiate conversations that make that experience more comprehensible, significant, and visible within the wider cultural landscape.

Context of the Research

Almost thirty years after the end of the war (1992–1995), the cities, villages, and landscapes in Bosnia and Herzegovina have been largely rebuilt. Although scars and wounds are still present, the built environment reflects the ways in which life continues. Many architectural projects and construction processes were perceived as symbols of hope—an unmistakable sign of faith in the future. Ibelings (2010) argues that the attempt to return to a “starting point” after the war is a myth, since the opportunity for a new beginning is, in fact, an illusion. While it is clear that nothing will be the same as before, it is also impossible to completely forget the past, which will always be embedded in the new reality.

Considering the state of the architectural scene in line with the political, social, and cultural context of the Republic of Srpska, it is not difficult to understand the complexity of working on a project such as *A.25 – 25 Years of the School of Architecture in the Republic of Srpska*. What is defined as contemporary architecture in the Republic of Srpska developed under extremely difficult conditions of post-war recovery, followed by processes of transition and privatization, then global financial crisis, and later by a large-scale construction boom enabled by informal

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financial flows, an unregulated real estate market, and the absence of systematic spatial governance (Milojević & Kuvač, 2021).

Even if we limit our view to the professional context of architecture and urbanism, the situation is far from ideal. Despite sporadic initiatives and short-lived organizations—such as the Association of Architects of the Republic of Srpska (established in 2007, inactive after 2012), the Association of Architects of Banja Luka (formally registered in 2022), and others—there is no professional architectural association in the Republic of Srpska. The Construction Industry Association exists within the Chamber of Commerce, but only formally and without substantial activity.

Many other structural elements that would regularly support architectural production at a professional level and help build a local architectural scene are also lacking—for example, a relevant professional journal, an architecture and urbanism portal, or a recurring architecture salon. For a while, two journals were active: *Contemporary Construction* (2009–2013), initiated by the Ministry of Physical Planning, Civil Engineering and Ecology of the Republic of Srpska, the Faculty of Architecture, Civil Engineering and Geodesy, the Institute for Construction, and the Chamber of Commerce; and *Prostor S* (2008–2013). The journal *SAG+* continues the tradition of the aforementioned *Contemporary Construction*, and is now published by the Faculty of Architecture, Civil Engineering and Geodesy of the University of Banja Luka with two issues per year from 2022. The Association of Architects of the Republic of Srpska organized the first and only *Architecture and Urbanism Salon of the Republic of Srpska* for the 1997–2007 period, which was held in 2009 at the Youth Center in Banja Luka.

In the meantime, a small number of engaged authors, architects, and urbanists have become part of the regional architectural scene, participating in exhibitions such as *Collegium Artisticum* (Association of Architects of BiH), *Salon of Urbanism* (Association of Urbanists of Serbia), *Belgrade Salon of Architecture* (Museum of Applied Arts), *Novi Sad Salon of Architecture* (Association of Architects of Novi Sad), *Ranko Radović Award* (Novi Sad), *DA! Student Festival* (Zagreb), *Balkan Architectural Biennale* (Belgrade), *Piran Days of Architecture* (Slovenia), *BIG SEE Awards* (Ljubljana), *EU Mies Awards*, *Days of Architecture Sarajevo* (organized by LIFT – Spatial Initiatives), *Days of Architecture Banja Luka* (organized by the Center for Spatial Research, with five editions between 2014–2019), and various other networks, initiatives, and groups.

In this context, the Faculty of Architecture, Civil Engineering and Geodesy—its Department of Architecture and Chair of Architectural Design—decided, on the occasion of the 25th anniversary of the study program of architecture (the school of architecture in Banja Luka and the Republic of Srpska), to take a retrospective look at the state of architectural production. With the support of the newly reestablished journal *SAG+* (published by the Faculty of Architecture, Civil Engineering and Geodesy, since 2022), and in collaboration with a wide alliance of partners—including regional universities, professional associations, architectural practices, public institutions, the construction industry, and others—the aim is to lay solid foundations for the next 5, 10, or 25 years.

MATERIAL AND METHODS OF WORK

The “A.25” exhibition is part of an ongoing research effort investigating post-war architectural production in Republika Srpska, serving as a preliminary, non-definitive snapshot of this field. It represents a pioneering attempt to systematically map, document, and present contemporary architecture and the formation of the architectural scene in the region. The study of architecture in Republika Srpska during 1997–2023 unfolds on several planes, employing various methods—primarily content analysis. Data were sourced from texts, photographs, drawings, plans, and other architectural records.

The primary source is direct experiential engagement with the built environment, assessing spatial quality in relation to historical, cultural, social, and aesthetic significance and its societal impact. This collection of firsthand observations, gathered by researcher-architects, was supplemented and validated through an open survey distributed among 23 faculty members across

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all five architecture-related departments at the Faculty of Architecture, Civil Engineering and Geodesy (architectural design, building technologies, urbanism, geometry & spatial visualization, heritage protection, architectural history & theory). Respondents included full-time and adjunct professors, researchers, and included representatives from professional associations, architectural practices, public institutions, the construction industry, and local government units.

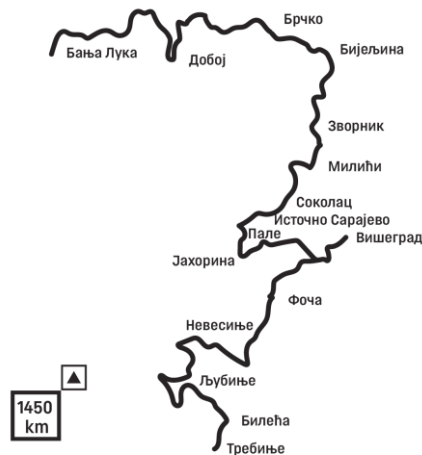


Figure 1. The map of the road trip - the journey which traced an intriguing cultural and landscape route through some of the most beautiful parts of Bosnia and Herzegovina. It followed a west–east axis — Banja Luka – Brčko – Bijeljina; a north–south axis — Bijeljina – Zvornik – Milići – Vlasenica – Han Pijesak – Sokolac – Pale – Jahorina – Rogatica – Višegrad – Foča – Gacko – Nevesinje – Bileća – Trebinje; and finally, a diagonal route from the southeast to the northwest — Trebinje – Ljubinje – East Sarajevo – Doboј – Banja Luka.

One challenge in our experiential approach was uneven territorial representation: architectural production beyond the Krajina region was under-researched. To address this, a fieldwork “road trip”—effectively a mobile research route—was organized (Karan et al., 2022). Traveling across Bosnia and Herzegovina became both a data-collection method and an analytical instrument (De Certeau, 1998), allowing us to experience aesthetics, observe transformations, conceive spatial imaginaries, and convert observed realities into hypothesized spatial narratives. The tour covered approximately 1,450 km across 20 cities and towns, mapping 66 buildings and producing around 900 professional-camera photos and 1,100 mobile shots. A post-tour photographic essay captured architecture in its immediate context. Although photography allows multiple readings, we deliberately minimized interpretive ambiguity between creator and viewer (Barthes, 1997; Hall, 1996).

A third data source was an open call addressed to architects, studios, bureaus, contractors, and other entities active within Republika Srpska to submit realized projects (up to four each) for the A.25 exhibition. The application form requested building name, function, location, author, contractor, design and completion dates, investment type (public/private), client information, site size, and condition. After three rounds, 30 respondents submitted posters for 120 projects. For missing data, curators formally contacted spatial planning departments across all 57 municipalities and 9 cities in Republika Srpska—receiving very low response rates and incomplete information.



Figure 2. Cover for the open call.

A systematic content analysis of all sources enabled identification and interpretation of architectural patterns, themes, and trends from 1997 to 2023, establishing selection criteria. However, the methodology has limitations. First, it reflects a narrow perspective on the “architectural scene,” often emerging from the networks of a few individuals (Strauss, 1990). Second, the field tour was constrained by time, budget, and technical resources, involving only two researchers over a few working days and limited to major travel routes—excluding other sites. Third, the poor culture of exhibition delivery hindered data completeness: few participants provided full project documentation, high-quality photographs, or detailed posters, which likely affected selection outcomes.

RESULTS AND DISCUSSION

The selection criteria for the A.25 exhibition are grounded in both European and global theories and practices of contemporary architecture, while also acknowledging the specific context of post-war Bosnia and Herzegovina and the unique geopolitical position of Republika Srpska, shaped by its emergence, development during transition, and everyday challenges. The criteria are defined as follows:

- Contextual integration: The architectural response to urban or natural environments, with adaptation to local culture, climate, topography, and spatial surroundings.
- Respect for natural and cultural heritage: Including the preservation of traditional architecture and cultural heritage elements, alongside the subtle introduction and contemporary interpretation of traditional forms.
- Functionality and rational design: Modern design emphasizing clean lines, functional forms, and absence of unnecessary ornamentation, reinforcing both aesthetic refinement and practical use.
- Innovation and contemporaneity: Encouragement of experimentation with new materials, technologies, and concepts, including unconventional spatial forms, sustainable materials, energy efficiency, and digital tools for planning and design.
- Technical precision: Evident in detailed materialization, construction techniques, thoughtful use of colors, textures, and light.
- Sustainability and ecological awareness: Including the use of renewable energy sources, efficient resource use, and integration of green spaces in the urban fabric.
- Cultural and social sensitivity: Addressing the needs of communities and contributing to inclusive spaces that foster social cohesion and local identity.

Given the importance of the process, the specific values of each individual project, and the aim to offer a comprehensive overview of architectural practice in Republika Srpska, all mapped projects were included in the A.25 exhibition and catalogue. Particular emphasis, however, was placed on those selected by the curatorial board. From over 150 preliminary selections and open call submissions, a total of 110 projects were considered for evaluation.

The curatorial board was composed of three renowned architects from neighboring countries—professionals equally active in both practice and academia—able to assess the projects with temporal and spatial distance. Through two rounds of evaluation, the jury selected 49 projects

showcasing the highest architectural and urban qualities. Additionally, in nine thematic categories (public open spaces, social infrastructure, small-scale architecture, multifamily housing, single-family housing, tourism facilities, commercial buildings, commemorative architecture, and religious architecture), one exemplary project was highlighted in each. To quantify architectural quality, a coefficient was defined based on the ratio of submitted to selected projects, using the following formula: $Aq = (\text{number of submitted projects} / \text{number of selected projects}) \times 100/10$

Typological Landscape — The Dominance of Market-Oriented Investments

A review of the typological representation reveals a dominant presence of commercial buildings—20 projects nominated, but only 9 selected—resulting in an Aq: 4,5.

The quality of commercial architecture reflects the prevailing business standards and economic conditions in Republika Srpska.

Social infrastructure ranks second with 19 nominated projects, but only 7 selected (Aq: 3,7), revealing the systemic problems of the public sector—marked by high levels of corruption, nepotism, and bureaucratic inefficiency.

Tourism facilities rank third, with 15 nominations and 8 selected (Aq: 5,3), largely due to the successful reconstruction of Yugoslav-era structures (1945–1992) and high-quality hotel complexes in prominent tourist destinations such as Mount Jahorina, Kozara National Park, Trebinje, and spa resorts in Banja Luka, Laktaši, and Teslić.

Multifamily residential-commercial buildings follow with 14 nominations but only 4 selected (Aq: 2,8), indicating alarmingly low design standards in the most widespread typology of built space. This decline—compared to the pre-1990 Yugoslav period—suggests an urgent need to prioritize multifamily housing in architectural education.

In contrast, single-family residential architecture demonstrates much higher quality: 7 out of 11 nominated projects were selected (Aq: 6,3). However, this does not reflect the actual spatial reality, as authored architecture represents only a marginal portion of the single-family landscape, which is largely characterized by informal construction without architects (Kuvač, 2017).

A similar pattern is seen in religious architecture, with 9 nominated and 4 selected projects (Aq: 4,4)—mainly due to the restoration of historic buildings—while the vast majority of religious structures are constructed without any reference to contemporary architectural practice.

Even more concerning is the state of commemorative architecture: only 2 of 5 nominated projects were selected (Aq: 4,0), while a large number of monuments display little or no architectural, urban, landscape, or artistic value.

The typology with the lowest performance is that of open public spaces, with only 3 out of 8 selected (Aq: 3,7). This reflects the lack of design competitions, institutional mechanisms, and broader systemic issues in planning and spatial culture.

The only typology with a fully positive outcome is small-scale architecture, showing an Aq: 10,0. Although the sample includes just five nominated projects, the results confirm that small-scale architecture offers a fertile ground for experimentation—free from most constraints of daily practice, apart from financial limitations.

Territorial Landscape — A Development Imbalance

The territorial distribution of contemporary architecture in Republika Srpska reflects its socio-political and administrative structure, as well as its geographic position within Bosnia and Herzegovina and the broader post-Yugoslav context. Two main development axes are evident—one extending west to east in the north, and the other north to south in the east—with significant disparities. The northern axis exhibits a more advanced level of architectural development compared to the eastern one.

In northern Republika Srpska, 68 buildings were nominated, with 32 selected. In contrast, the eastern region had 44 nominations, with only 13 selected. These figures mirror the demographic and urban concentration in the north, particularly around Banja Luka—the largest city and administrative center—where 35 projects were nominated and 21 selected, yielding a success rate of 60%. Prijedor follows with 8 nominated and 5 selected projects (Aq: 6,2), reflecting the existence of a modest yet active architectural scene, supported by a cultural environment and the

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influence of engaged individuals whose work significantly shapes the local spatial culture. Brčko stands out with a large number of public and commercial buildings, owing to its special administrative status within Bosnia and Herzegovina (Milojević, 2015).

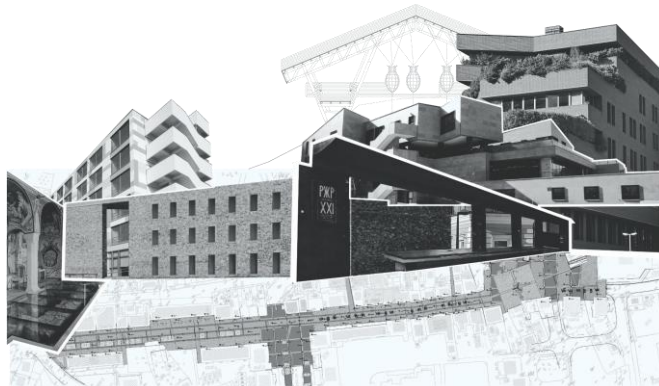


Figure 3. Collage of the architectural landscape of Republika Srpska: religious building – Cathedral Church in Ljubinje; public building – Student Dormitory, Banja Luka; commercial building – Administration Building of the Drina Hydropower Plant, Višegrad; small-scale architecture – Detlačke Granaries; tourist facility – Šeher Spa; memorial architecture – Monument to Fallen Miners, Prijedor; public space – King Petar I Street, Prijedor; mixed-use residential building – corner of First Krajina Corps and Olympic Champions streets, Banja Luka.

However, the architectural quality is low—only Aq: 2,8 success—indicating weak development policies and governance. The architectural landscape in the eastern part of Republika Srpska is similarly indicative of broader developmental imbalances. Bijeljina, though a city undergoing growth, yielded only 3 selected projects out of 6 (Aq: 5), suggesting missed opportunities to guide development through higher-quality urban and architectural design. East Sarajevo had the highest number of nominations in the east (11), and the second-highest in the entire entity, but with a dismal Aq: 1,8. Despite being a newly planned and constructed city (Kuvač, 2020), it failed to capitalize on the “blank slate” potential to deliver architectural excellence.

Two tourist centers somewhat improve the average quality in the eastern region. On Mount Jahorina, a now-urbanized Olympic mountain, only a few notable examples stand out—Hotel Alpin by A4 Studio (2019) and Hotel Termag by Amir Vuk Zec (2012)—yielding an Aq: 4. In Trebinje, the tourism capital and regional center, the Aq reaches 5, primarily due to a reconstruction of a historic building (Church of the Peter and Paul Monastery, arch. Milijana Okilj and Radoslav Beleslin, 2007) and a few outstanding single-family homes (House on the Trebišnjica River, arch. Miloš Milivojević, 2023). However, the bulk of new multifamily housing and tourist infrastructure reshaping Trebinje’s urban landscape fails to meet minimum architectural standards.

As with Prijedor, the relatively high number of nominations for a small city like Trebinje suggests a degree of spatial culture and architectural awareness. This is supported by periodic exhibitions and festivals such as *StartArt! Fest*, *KRŠ* (Trebinje 2023), guest exhibitions of *Collegium Artisticum* (2017–2018), the *Salon of Architecture and Urbanism of Republika Srpska* (2007), and the *Herzegovinian Salon of Architecture* (2017).

Landscape Over Time

The development of contemporary architectural production in Republika Srpska can be divided into three main periods, each reflecting key social and political events. The first spans from 1997 to 2008, but also includes the years immediately after the signing of the Dayton Peace Agreement (1995–1997), as well as several exceptional buildings designed during the war years

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(1992–1995). Within this period, two subphases are evident, with 1999 marking a turning point due to the escalation of the Kosovo conflict and NATO's intervention in the Federal Republic of Yugoslavia. At this time, the architectural scene in Republika Srpska was enriched by a number of engineers and architects who relocated and began working, primarily in Banja Luka.

This period includes 32 nominated buildings, or 29.09% of the total sample. Most were built in Banja Luka (8), Brčko (6), and Prijedor and Trebinje (3 each). The dominant typologies are commercial (7), public (7), religious (5), and open public spaces (4). The most productive year was 2007, with seven realized projects. Among the highlights are: the Cathedral of the Nativity of Christ in Ljubinja (arch. Ljubiša Folić, 2004); the Memorial to Fallen Miners in Prijedor (arch. Vladimir Milić, 2005); and King Peter I Liberation Street in Prijedor (arch. Saša and Malina Čvoro, 2007). The global financial crisis of 2008 marked the end of this 11-year period, disrupting the postwar recovery of the construction industry.

The second period (2009–2020) also lasted 11 years and was defined by stability and continuity in architectural production. A total of 55 projects were nominated, representing 50% of the total corpus. Banja Luka remained the center of activity (19 projects), followed by East Sarajevo (6), with additional contributions from Jahorina (3), Pale (1), and Bijeljina (3). The most frequent typologies were commercial and tourist buildings (11 each), followed by multifamily housing (8), single-family homes (7), and public buildings (8), along with two small-scale architectural works.

Five standout examples from this period include:

- Mixed-use building at the corner of First Krajina Corps and Olympic Winners Streets, Banja Luka (arch. Nebojša Balić, 2011);
- Detlačke Ambarine archaeological site near Derventa (arch. Milan Aleksić, 2013);
- Administration building of the Drina Hydropower Plant in Višegrad (arch. Branislav Mitrović, Ognjen Krašina, Siniša Tatalović, 2013);
- Student Dormitory in Banja Luka (2015); and
- Čvoro Family House in Banja Luka (2017), both by Malina and Saša Čvoro.

The most productive year in this phase was 2020, with 8 realized projects, followed by 2013 (7) and 2018 (6). The third and most recent phase spans from 2020 to the present. With 25 nominated and 13 selected buildings (Aq: 5,2), this period shows the highest levels of production and architectural quality. The data reflect both a significant increase in output and quality, as well as a possible lack of historical distance for objective evaluation. Most projects were built in Banja Luka (9), followed by Trebinje (4), East Sarajevo (2), and Jahorina (2). The dominant typologies include multifamily (4) and single-family housing (4), tourist buildings (5), and both commercial and public buildings (4 each). The most productive year was 2023, with 11 projects, followed by 2022 (10) and 2021 (6). Only one building was singled out as exemplary in this period: the Šeher Bath in Banja Luka (arch. Miomirka Dragomirović Trbić and Bojana Grebenar, 2023).

CONCLUSIONS

Average Evaluation

Ibelings (2010) noted that architecture in Bosnia and Herzegovina from 1995 to 2010 reflects the values of a postwar architectural culture—one that had to be rebuilt from the ground up, reconnect fragmented threads, and reoccupy physical and conceptual space, ultimately achieving this in an intriguing manner. Diversity and scope make this culture particularly compelling. Despite this diversity, a common image emerges—best described as a “mixture.”

A review of the development of contemporary architecture from 1997 to 2023 reveals an incidental narrative, offering insight into the social, cultural, and economic contexts that have shaped the built environment. One of the most prominent themes is the stark imbalance between private and public investments, with private, market-driven projects dominating the scene. Most architectural production is initiated by private clients, while few public investments are limited to administrative buildings, open spaces, or commemorative monuments. Public service architecture—schools, elderly care homes, and health facilities—is significantly underrepresented.

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Projects based on open architectural competitions remain rare but consistently represent the highest quality. This indicates a broader societal disregard for architecture as a cultural and social value—typical of post-transitional societies (Rot-Cherina in Kuvač & Čvoro, eds., 2024).

The lowest-rated typology is multifamily mixed-use housing (Aq: 2,8), suggesting an urgent need for intervention in this area. In contrast, the highest-rated is small-scale architecture (Aq: 10,0), which deserves continued support. The highest quality is found in the northern part of Republika Srpska, particularly in Banja Luka (as the political center) and Prijedor (as a place with an established culture of space). Bijeljina and Trebinje serve as poles of development in the eastern region, though with underused potential. Alarming low quality is observed in East Sarajevo and on Mount Jahorina—despite their volume of production and the expected high standards of living and tourism infrastructure.

A New Beginning

Precisely because of a fragmented architectural scene and the lack of institutional support, any effort to retroactively document, select, and evaluate architectural production becomes immensely valuable. Such efforts can lay the foundation for future retrospectives and professional associations. Symbolically and practically, the new building of the Faculty of Architecture, Civil Engineering and Geodesy at the University of Banja Luka marks a new beginning. As a realization embodying the best ambitions of the reconstructed scene, it stands as a platform for its inauguration. From this physical space—now a new home of architecture—a platform for dialogue, collaboration, and systemic engagement can be envisioned. It may become a site for fostering initiatives such as professional associations, journals, exhibitions, awards, critical practice, cross-disciplinary networking, and potentially a center or laboratory for contemporary architecture (Rot-Cherina in Kuvač & Čvoro, eds., 2024).

This exhibition confirms the importance of continuous monitoring, documentation, and public presentation of architectural work, supported by research and publishing that strengthen the institutional and cultural infrastructure of the discipline. It is precisely through systematic retrospectives that the language of the scene is formed, a culture of mutual evaluation is cultivated, and ongoing production is encouraged. Retroactive reconstruction of architectural practice enables a shift from individualized task responses to the recognizable shaping of spatial culture—uncovering common threads, forgotten approaches, and deeper contextual meanings within the built environment.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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DESIGNING THE BRIEF: PRINCIPLES FOR SHAPING THE ARCHITECTURAL DESIGN CURRICULUM FOR HOUSING

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ABSTRACT

Learning to design architectural spaces intended for everyday inhabitation – houses, apartments, apartment buildings – represents one of the most important steps in the education process of an architecture student. Such a step, appropriately, demands a carefully prepared practical curriculum, and within it, an architectural brief created and curated through a valid set of parameters. This paper aims to present and further examine the principles used in creating appropriate architectural briefs for housing design studio courses at the University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy.

Methodology of the research is comprised of juxtaposition and cross-referencing of several key influences:

- understanding of the overall students' learning trajectory, both as intended by a school curriculum, as well as observed through educational practice.
- understanding of the local and international context of housing (including the valuable collective housing heritage of Yugoslavia)
- accumulating body of educational experience acquired over the years through different types of briefs and through specific response of students to those briefs (through design proposals).

Results and further analysis dictate specific sets (clusters) of brief design: contextual range (natural to suburban to urban), topographic range (flat vs. sloped), scale (housing ensembles vs. individual houses), scope of intervention (green-field or interpolation) and type of intervention (collective vs. atomized).

Keywords: housing, architectural brief, housing heritage, architectural education.

INTRODUCTION

Formal architectural education represents quite a short period intended for adoption of a very wide set of skills. Some of the most notable of these skills include: the ability to produce accurate technical drawings (with data sets), the ability to discern converging socio-economic facts in specific contexts, the propensity towards a simple visual communication of ideas, the application of critical thinking and, above all, the ability to enter the design process for building types one has never learned at school in locations one hasn't designed in before. This required skillset is certainly meant to be accompanied by a set of knowledge (in traditional sense and form). Also, certain elements and principles of architectural design are indeed transferable from one building type to another and from one environment to another. However architectural design remains at all times an art and a craft of safely and gracefully landing on an unknown contextual (and literal) terrain, while at the same time conveying (un)certain (legible) messaging (Milić Aleksić, 2022, p 57).

In order for this design-oriented worldview to be developed the educational process needs to include several key steps, both for the sake of learned elements and acquired skills. Some of the most important of those steps are comprised of design assignments related to everyday inhabitation by human beings: houses, apartments, as well as systems, conglomerations and ensembles of these. It is beyond obvious that housing does represent one of the oldest, most common and most widespread forms of architecture, and as such it needs to be studied extensively. What might not be

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obvious – and that is our contention here - is that residential architecture represents one of the foremost tools for shaping the design-thinking oriented mind. Further, our inquiry aims to arrive at specific parameters which, when adjusted, would further bolster this ability of housing curriculums to forge new architects.

The research and discussion presented herein is based and nested in the teaching practice at the University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy, where all of the paper's authors teach in design studios dedicated to individual and collective housing, while also participating in those studios which precede and also follow the housing studios within the progression of building typologies.

THE TEACHING ENVIRONMENT AND STRUCTURE OF THE CURRICULUM

Architecture studies at the University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy ('Faculty' proceeding forward) are guided by an official academic curriculum, which is, at the time of this writing, in its fifth year of official use (University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy, 2018). This curriculum represents a long overdue reform. Its predecessor was structured through more strictly segregated compartments, aimed at acquisition and assimilation of specific sets of knowledge (auxiliary to design) which were subsequently expected to be applied in design tasks. These design tasks were, on their part, structured through a sequence of increasing complexity, and increasingly diverse typology: from simple (programmatically non-binding) exercises, through simple shelters, onwards to houses, apartment blocks, then to office work, leisure, hospitality and further to specialized spaces for agriculture, simple industrial facilities, transportation buildings, healthcare etc. Main limitations of this approach consisted in limited allocated time for both the knowledge application to occur, and for specific processes of design thinking to express themselves adequately (we will deal with these processes further in text).

The new curriculum placed the design studio course at the core of the educational progression. Design studio – a staple of architectural education – sets both the knowledge acquisition and knowledge application within the framework of a particular design process, thus aiming for more integration (Salama, 1995, p 77). A few examples might help the elaboration: Skills related to graphical representation and communication, otherwise (that is: in an older traditional segregated framework) developed in separate courses, in studio become a part of the design process, as well as the part of the ideas/solution presentation. Also, elements and aspects related to structural integrity, material finishes, services, plumbing (etc.) instead of being practiced on generic templates, are, in a design studio environment, practiced on one's own design proposal, (semi-)simultaneously with this proposal being conceived and drafted.

The design studio model still proved to have its limitations. Most usually, the limitations would be perceived as a lack of real-world simulations (Salama 1995, p 11) or being related to the quality of auxiliary subjects, taught through design (Hettithanthri & Hansen, p 2355). For example, by refraining from standardized templates the learning process would be prone to imprecisions. Also, the complex tasks of design process would subtract in time allocation from auxiliary knowledge, the design achievements would dominate in evaluation etc. However, seldomly is it perceived that the studio model places significant strain on the design learning as well. This strain is not acutely felt within individual studios or design assignments but is constituted on the totality of a four-year span of formal architectural education (four years in case of this curriculum, and it might be three to five in others). The strain thus consists of the limited number of opportunities for a student to engage in a (complex) design process and limited number of types of design tasks – all because of the complexity and great time portions that are allocated to individual design studio assignments. As we shall see later, the composition of the design task and design brief for housing studios needs to address this theme as well.

RESIDENTIAL ARCHITECTURE AS A DESIGN TEACHING TOOL

The aforementioned Faculty curriculum places housing/residential subjects at the second year of studies, with individual housing (a single-family house) being thought/designed in third

semester and collective housing following in fourth. While there remains a certain doubt whether a second-year student is adept enough to engage all the complexities of residential architecture (Taraszkiewicz & Taraszkiewicz, 2022, p. 220), this position in the curriculum does correspond adequately enough with the pronounced importance of housing architecture in design education. Before we proceed, however, this “pronounced importance” needs some additional elaboration and verification. There are several aspects to consider:

The first aspect to consider is that housing is the only architectural programme that practically every student is deeply acquainted with. Spaces intended for education (all manners of schools etc.) are indeed similar in that regard, but the overall length, as well as practical and emotional depth of experience of houses and apartments (both those inhabited and visited) is unrivaled. This makes residential design assignments the most solid and most rooted starting point for learning to design around complex programmes – even if student’s designs (while trying to emulate the most accomplished contemporary residential architecture) for the most part in the end surpass scale, complexity and quality of spaces most students have had the experience of inhabiting.

Second, housing architecture – but almost exclusively the architecture of a (contemporary) single family house - maintains a very good balance between functional necessities on one side and expressiveness of architectural form on the other. (In case this needs additional explanation, extremes of the spectrum will prove sufficient: sacral architecture, for example, is guided predominantly with – inner and outer – form, while an industrial facility leaves little outside strict spatial-technological processes. A house escapes neither influences.) Additionally, contemporary architecture of a single-family house tends to readily express its programmatic content in its (outer) form, rarely having to perform any type of “form-content” balancing act. All this, again, makes a house an appropriate tool of design learning.

Third, these two subsequent design courses form a unique node in the progression of architectural design education. A house represents a culmination of that strand of architectural design thinking which is centered around human body and around human perception of environment. All the anthropometry studies of the early phases of education primarily converge on human abode. Individual house is the major point for this convergence. At the same time, collective housing represents a starting point for thinking about architecture in terms of systems, structures, rhythms and repetition. For students, collective housing marks the beginning of this new outlook on architecture, while still being firmly connected to individual housing and the general rules of design intended for dwelling spaces.

It is important to note (or simply to remind) that residential architecture, besides being a “useful tool” in design education is also a crucially important subject. The vast majority of architects (professionally active in domains of architectural design) are set to often deal with matters of residential architecture, either in single- or multi-family housing, either in interior or integral architectural design. This assertion stands as especially true in the context of Bosnia and Herzegovina and neighboring countries, which is the primary geographical area of interest for the faculty. It is a region whose most dominant form of architectural production are collective housing units and ensembles (Agency for Statistics of Bosnia and Herzegovina, 2025).

PARAMETERS OF A DESIGN ASSIGNMENT

Since we have introduced residential architecture as a subject of particular interest and importance in design education, by the same token we have argued for the increased attention to be given to the job of structuring the housing design studio assignments. Previous elaboration has also raised some important individual subjects, which will need to be addressed in the formation of the parameters.

It is necessary to first set a working version of a model assignment. (A separate and a more voluminous exploration is possible as to ascertain what a model design assignment might look like, but for the purposes of this paper we will simulate in on the basis of a typical one.) An assignment for a housing design studio might be defined as a formal request for a design proposal, defined by:

- A set of hypothetical users. These are most commonly, but not exclusively, inhabitants, as pertaining to the theme subject.

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- Approximate intended way (and mode) of use for the requested piece of architecture. These first two aspects are what is generally referred to as a *brief*. In other words, a brief is set of requirements (predominantly programmatic and functional, often vague), but can also be described as a cluster of intended/possible scenarios of building's use. It is thus semi-specific and only defines intentions, wishes and broad limitations, while the final design proposal would be able to form a single scenario thread out of the bundle of possibilities.
- Contextual settings. These diverge greatly, and are generally set through location and socio-economic context (or scenario). Location fans out into a very diverse set of natural and artificial factors, with both being either hard (limitations) or soft (influences).
- Processual requirements. These, to lesser or greater degree, dictate the way and the phases through which the design proposal will be guided and developed. It also defines the confines, level of detail and other requirements of the end product. It can also proscribe elements of authorship (for example by requiring a certain amount of team work etc.).
- Procedural requirements, which simply dictate timetables, deadlines, evaluation system etc.

Having by now described in general all the key elements for understanding the context of housing design studio, we can proceed to examination of the parameters which shape the design assignment. Here we propose a set of six parameters, which between them should be able to address all the previously mentioned themes and issues.

Brief flexibility. For students to be able to fully explore the interconnectedness of form and programmatic content in residential architecture, the brief must not remain too fixed. However, the residential programme generally is rather fixed. Main elements of sleeping, preparing and eating food, spending leisure time together (etc.) in most instances cannot be significantly altered (Ugljen-Ademović, 2018, p 37), however exaggerations of individual elements and additions to the basic programme should be permitted. Examples include pronounced home study spaces, home workshops or small business (for single family housing) or pronounced communal and shared spaces (within collective housing). In terms of users/inhabitants, changes which permit increased number of children in the family should be permitted but we have observed that this type of change is rarely employed by students, since the additional individual rooms rarely provide any help in terms of creating good architectural composition. Another change proved to be much more interesting, especially in individual houses: addition of a third (senior) generation, which requires the establishment of interesting new setups of both privacy and space sharing.

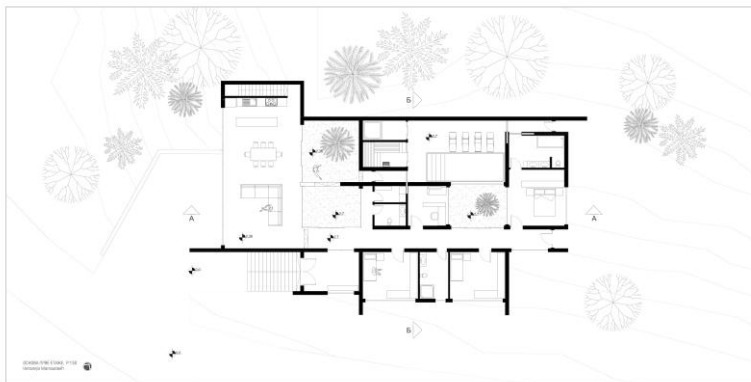


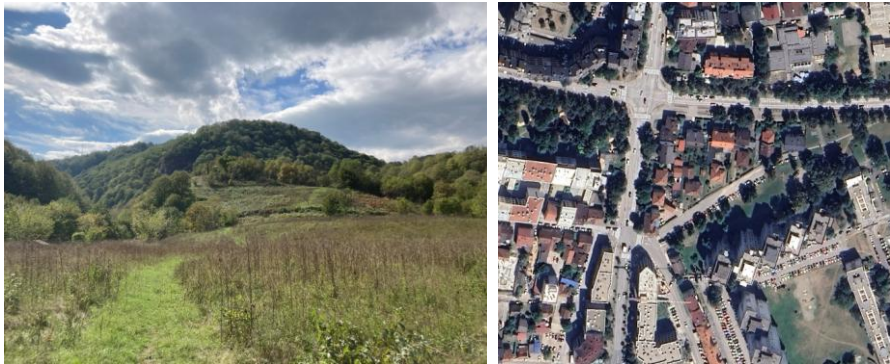
Figure1. Programme of a single-family house with pronounced elements of leisure. Although this example is still well within the bounds of a standard residential programme, it is notable how the brief complexity allows student to explore a particular house configuration with multiple inner courtyards. Student Natalija Malešević, Studio project 3 2023/2024.

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Allowing for changes which transform the brief somewhat beyond housing also addresses some of the previously mentioned limitations of large design studios: even very traditional and fixed assignments (like housing) approach the realm of hybrid and became a complex design exercise.

Site selection range. This parameter is mostly related to the nature-to-urban spectrum: from houses in nature (or countryside), to suburbia, to townhouses in relatively dense city-centers. Collective housing does not have this wide spectrum, since apartment blocks are not usually intended for undisturbed nature. Also, collective housing has less educational use for this variability, due to its scale.

How is site selection important then and how is it optimized and used for design assignments? For a house design, the lessons from those different points on the spectrum are quite different: from emphasizing primary form and use of open spaces in large plots and natural surroundings to emphasizing secondary and tertiary form, privacy, efficient use of space - but also finer aspects of fluidity, permeability, dichotomy etc. (Nikezić, 2018, p.81) - in dense urban settings. Complete optimization – which would teach all or most of these lessons in a single assignment – is rarely possible, and this represents one of the major instances of limitations placed on the design education by the large design studio model and its limited number of design opportunities throughout the duration of the formal studies. One coping mechanism is for the teaching staff of the studio to gain a certain experience through year-to-year variation of the type of assignment site, with this experience then being transferred through other elements in curriculum, other than studio. However, there are other possibilities for optimization of this parameter, and they fall mainly into two options. The first one is to select sites which lie in rare and peculiar positions of interaction between dense urban fabric and relatively large elements of natural surroundings. Examples in our studio experience are mostly related to rivers (especially those with unregulated und well vegetated banks) during their run through urban settlements. The other possibility is actualized when the assignment dictates a location in nature, but mandates first a step of urban design and insists on first installing a (dense) cluster of houses, with one (or more) being later selected for further design. Thus, both sets of concerns (nature and urban related ones) are being simulated in the assignment.



Figures 2 & 3. Site selection range, from country side (left, Studio project 3 2024/2025) to diverse urban fabric (right, Studio project 4 2023/2024). The Studio project 3 location (left) features a high importance of parameter C (topographic range and variation), while the urban location of Studio project 4 features a wide variety of options under parameter E (scope of the intervention).

Topographic range and variation. While there are some interesting design avenues to be explored in differing topographic elements with regards to collective housing (cascaded patterns for example) this parameter is predominantly useful (and used) for individual housing assignments. There, when coupled with the solar orientation of the (sloped) location it has a particularly high educational potential. A sloped location accentuates the questions of (dis)continuity of the form of landscape and the architectural form. It also increases the complexity of the relations between approach, privacy and view.

The first distinction in this parameter is that between the (relatively) flat and the (more or less) sloped terrain. The second distinction is concerned with approach: descending or ascending towards the house. It is this second distinction which often carries the most complex lessons of house design, and which is thus very valuable for use in assignments. However, it is an either-or parameter as a student only designs a single house. What provides a remedy for this situation is the one aspect of design studio which we haven't addressed previously. In studio, knowledge is acquired, transferred and actually produced in multiple directions: from teacher to student, certainly from student (or work with students) to teacher, but also from student to student (Crowther, 2007). Having this in mind, certain assignments are shaped in a way for students to freely choose between micro-locations with ascending or descending approach. As a result, there are both cases within the pool of design proposals, and since students are acquainted with one another's work throughout semester, all relevant lessons become showcased.

Scale of the intervention. This parameter is mostly related to the question of whether there are urban design tasks to be performed prior to engaging in architectural design of individual piece of residential architecture. Scale however, can vary also at the level of that individual piece, especially within the domain of collective housing. In our teaching practice and research, we have not by now discovered an effective way to make a single student practice (architectural) design in significantly differing scales on a single assignment. Even the option of having differing cases within the whole of a studio (as described under parameter C) is rarely applicable, precisely because the scale acts as one of the primaries determining factors between different assignment options. One workaround tactics we occasionally employ in collective housing assignments is to allow for a segmented finish and detailing of large-scale buildings - if the primary structure by itself allows at least a minimum of this segmentation. Also, it is allowed only in cases where this segmentation is applied in horizontal plane, so as to every segment is a complete structural element (with a foundation, structure and a roof. (In other words, no division of vertical tall structures into stacked segments is ever allowed.)

Outside of the workaround described there also remains the approach of varying the assignment scale from year to year, in an attempt to gain valuable experience for the studio staff.

Scope of the intervention. The parameter of scope deals with ways in which micro-location can be treated. The three main poles within the "triangle" of options could be described in a following way:

- The micro-location represents a valuable context (either natural or built) into which the new design needs to thoughtfully insert itself with the intent of building upon the existing qualities.
- The location is so called "green field", i.e. mostly vegetated/agricultural land, but without prominent features which would make the case for their preservation or integration into the design. In terms of the logic of assignment creation, many "brown fields" would be included into this category (and certain brownfields would fit the category 1).
- The micro-location is in certain ways rich and complex but should/will be disregarded, and the new state of things would be established in place with the design proposals. This is the usual (almost a caricatural) scenario of a lively poor neighborhood being replaced with a new real estate development, and as such it is an extreme (a "pole" in this elaboration) and is rarely employed in pure form in assignments. It is also different from most cases of "brown field" described under 2, in that it often values the context right outside of the perimeter of the space intended to be ignored (or "razed").

The usual approach regarding this parameter is to favor that location which offer some level of overlap between the three described poles. Within such a setup, students individually choose which scenario and pole to more closely pursue. Still, it is highly valuable to always have some level of pole 1 in many assignments, and not necessarily in order for students to deal with valuable features on-site, but more in order to introduce some "hard" (unchangeable, un-negotiable)

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limitations into their design calculus. Also, as Allen notes, “Working with and not against the site, something new is produced by registering the complexity of the given” (Allen, 2009, p 216).

CONCLUSIONS

Education in the field of architectural design is predominantly carried within a course setup called design studio. It is the case in many institutions of higher education throughout Europe, North America and other parts of the world. Since the introduction of the new teaching curriculum for architecture studies in 2019 it is also the case at the University of Banja Luka, Faculty of Architecture, Civil Engineering and Geodesy, where this research (with its underlying teaching practice) was based. The main premise of this paper was that, for students, learning to design within the field of housing (from individual to collective) represents one of the most important steps in becoming steeped in architectural design overall. As such, this important step would need a carefully shaped curriculum, which would reflect these wider design considerations, while also addressing even some limitations of the design studio educational model. More narrowly, this curriculum would ideally need to be year-to-year (consciously and intentionally) adjustable with regards to every major factor of the architectural design assignment: users, intended way of use (these two roughly constitute what is known as a brief) and contextual settings.

Our paper determined five major parameters of curriculum composition, together with options for their adjustment. These parameters include: brief flexibility, site selection range, topographic range, scale of the intervention and scope of the intervention. Some of the parameters proved to be relatively easily adjustable in a way which offers more design lessons within a single semestral assignment (for example, site selection). Others needed more complexity in order to deliver good teaching outcomes (for example expanding the brief beyond simple housing), while some parameters remained an either-or option, only allowing for expanded design lessons to be obtained indirectly (by relying on previous years' results). This paper certainly does not exhaust all the possible parameters and there also remains a promising area of research on the role of housing in architectural design education, especially if elements of time separation are brought between courses on individual and collective housing or if certain (housing) elements of the curriculum appear cyclically.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper

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THE ROLE OF CURRICULUM AND METHODOLOGY IN TEACHING ARCHITECTURAL DESIGN

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ABSTRACT

This paper analyzes approaches and methods for teaching architectural design at the undergraduate level, focusing on office and administrative spaces at the Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka. The study examines how curriculum structure and methodological strategies influence the development of students' design competencies.

The methodology combines theoretical analysis of design studio pedagogy with qualitative evaluation of teaching practices, project assignments, and student work across multiple generations. The study analyzed pedagogical factors, organization of the design process, use of analog and digital tools, student-mentor collaboration, and the role of site context in concept development.

Findings reveal a dual approach to learning: (1) an adaptive curriculum that responds to students' abilities, prior knowledge, and thematic variations; and (2) a methodological framework based on iterative revisions, tool integration, and collaborative work, fostering analytical, conceptual, and presentation skills.

The study confirms that a clearly defined and adaptive curriculum, combined with structured methodological strategies, enhances the quality of architectural design education and effectively prepares students for professional practice.

Keywords: education, design studio pedagogy, live architectural models, project reviews

INTRODUCTION

In the contemporary context, marked by dynamic changes in social, technological, and professional circumstances, architectural education faces the ongoing need to adapt its objectives and teaching methods. A key role in this process is played by architectural design, as the core discipline within architecture study programmes, through which students not only acquire methods for shaping space, but also develop creative abilities, analytical thinking, and professional attitudes necessary to respond to the challenges of contemporary architectural practice.

Within this framework, the design studio has, for decades, represented the fundamental form of architectural education worldwide. At the same time, it stands as the central component of the Architecture programme at the Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka (hereinafter: the Faculty). Based on the principle of *learning by doing*, the design studio enables students to develop skills of analysis, synthesis, and expression in the design process by simulating real architectural problems (Schön, 1987; Salama & Wilkinson, 2007).

Although the role of the design studio is clearly defined, practical experience indicates the need for a continuous improvement of the teaching process—particularly in terms of selecting design assignments and structuring the curriculum in line with contemporary social challenges and the dynamic conditions of the professional environment.

The aim of this paper is to analyse and enhance approaches and methods of teaching architectural design at the undergraduate level, by examining experiences and outcomes of design studios implemented at the Faculty of Architecture in Banja Luka. A particular focus is placed on Design Studio 7 – Work and Leisure Spaces, used as a case study, analyzing project assignments

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related to office and administrative spaces, with the aim of identifying potentials for improving teaching models and more effectively guiding the development of students' design competencies

Accordingly, the research seeks to:

- present the theoretical and pedagogical foundations of architectural education, with emphasis on the design studio as the primary didactic platform;
- analyse the structure and specific characteristics of the design studio curriculum in the Architecture programme at the Faculty in Banja Luka;
- examine how carefully conceived design assignments contribute to the systematic development of students' design competences;
- indicate possible improvements to teaching approaches and methodologies in architectural design.

In this way, the paper aims to contribute to a better understanding and more purposeful direction of educational practices that shape the contemporary competences of future architects, in accordance with the needs of the profession and the dynamic evolution of spatial typologies.

MATERIAL AND METHODS OF WORK

evaluating and improving the curriculum of architectural design education at the undergraduate level. The theoretical framework includes a review of relevant literature and contemporary pedagogical approaches to design studio teaching, emphasizing the role of the studio project in developing students' design competencies and critical thinking skills.

The empirical component was conducted through a detailed analysis of teaching practices within the Architecture undergraduate program at the Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka. Particular attention was given to Design Studio 7 – Work and Leisure Spaces, with data collected and analyzed regarding the structure and content of the project, including course syllabi, project assignments, student work, documentation of public presentations, and observations of student–mentor interactions. The analysis focused on evaluating student outcomes, curriculum integration, and the role of different spatial programs in shaping students' understanding of function, form, and structure.

Special emphasis was placed on the organization of the design process, including the alternating use of analog and digital tools, collaborative problem-solving, and iterative project reviews. This approach enables a systematic assessment of pedagogical factors and concrete student outcomes, providing a foundation for recommendations to enhance the curriculum and methodological framework of the design studio.

Theoretical framework: design studio pedagogy

Contemporary architectural education focuses on acquiring design methods and developing creative, analytical, and critical competences through direct engagement with real and simulated spaces and functional challenges, preparing students for the complexity of professional practice. The central element of this process is the design studio, which for decades has been recognized as the fundamental pedagogical model in architecture schools worldwide (Schön, 1987; Salama & Wilkinson, 2007).

The design studio is based on the principle of “learning by doing,” where students develop the competences necessary for independent and responsible design through practical assignments. Unlike traditional academic methods, this pedagogical form emphasizes the development of knowledge and skills through concrete design tasks, classifying it within competency-based and project-based learning approaches (Salama, 2015; Schön, 1987).

Donald Schön (1987), a prominent philosopher and educator, defines the design studio through four key dimensions: as a specific culture of collaboration and shared learning between instructors and students; as a physical space for conducting this process; as a particular mode of teaching; and as an organized sequence of activities and assignments structuring the curriculum. This holistic approach highlights both pedagogical and social aspects of the studio environment (Schön, 1987).

Within this specific educational setting, intensive one-on-one interaction between mentors and students enables dynamic knowledge exchange and the creation of innovative solutions. Students confront complex problems similar to real professional situations, solving them through iterative experimentation and evaluation processes with continuous mentor support (Dulić, 2021; Candy, 2006).

Through the design studio, students develop three interrelated competences: a specific mode of architectural thinking, the architectural language used to express that thinking, and technical skills in drawing and visual representation (Lawson, 2006). These skills can be fully acquired only through practical work and solving real design problems, which the design studio facilitates (Schön, 1987). In this context, the design studio represents the framework within which the curriculum is implemented through a concrete design process – analysis, conceptualization, and presentation of architectural solutions. It forms the core teaching methodology of architectural education, serving as the medium through which pedagogical goals and curricular contents are put into practice (Salama & Wilkinson, 2007; Schön, 1987).

However, challenges arise in implementing this model, especially when methodological approaches are not adapted to beginner students lacking experiential knowledge and intuitive understanding of design processes. Recent researchers emphasize the importance of introducing phased and structured methodologies that clearly define techniques and tools, as well as the significance of clear visual and graphic representations that facilitate learning and adaptation to complex tasks (Oxman, 2008). This enables more efficient progression in competency development while reducing frustration and increasing motivation among students (Cennamo & Brandt, 2012).

In this sense, the design studio remains a key component of the curriculum, requiring continuous reflection and adaptation of pedagogical methods to respond to the challenges of contemporary professional practice and the needs of new generations of students.

Case Study: Analysis of the Curriculum and Outcomes of Design Studio 7

The undergraduate program in Architecture at the Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka, has been implemented in accordance with the officially accredited academic curriculum since the 2020/21 academic year. Within this curriculum, the design studio constitutes the central pedagogical component of the program, structuring the educational process and enabling the continuous development of students' knowledge and competencies throughout all years of study, in alignment with the theoretical and pedagogical foundations outlined above.

The teaching of architectural design at the Faculty, organized through design studios, is structured to gradually introduce typological categories of design: from introductory exercises and small-scale projects, through individual and collective housing (third and fourth semesters), to more complex programmatic structures such as work and leisure spaces (fifth semester), and hybrid programs (cultural, healthcare, etc.) in the final years of study.

Within this chronologically organized framework, in the fifth semester, Design Studio 7 – Work and Leisure Spaces represents the first systematic exposure of students to public programs and more complex urban contexts.

The research presented in this paper encompasses an analysis of teaching practices in Design Studio 7 over three consecutive academic years under the new curriculum, enabling the monitoring of methodological consistency, evolution of teaching strategies, and selection of design tasks. The collected data include archives of student projects, course syllabi and project briefs, informal discussions with instructors and students, and documentation of public presentations. Each cohort comprised approximately 50 to 60 students, with a weekly schedule of 4 hours of lectures and 5 hours of exercises.

The methodological approach of this study is grounded in qualitative and content analysis of the Design Studio 7 curriculum, combined with a systematic review and interpretation of student work produced during three consecutive teaching cycles. Particular emphasis was placed on the

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formative evaluation process, conducted through multiple stages of assessment and feedback throughout the semester.

The research was carried out within the framework of standard teaching practices at the Faculty, with all authors of this paper actively engaged in the implementation of architectural design education.

Teaching in Design Studio 7 has expanded in scope compared to previous years, where the primary focus was on residential design. This expanded structure facilitates the introduction of diverse programmatic requirements and familiarizes students with more complex architectural typologies. However, it also poses a challenge for the teaching team in formulating pedagogically relevant and stimulating project themes, as well as in selecting locations that provide design challenges conducive to high-quality studio assignments.

Over the past three academic years, two key design topics have been developed within the studio, both centered on administrative spaces with complementary programs:

"Dream Laboratory – Center for Architectural Research";

"Conceptual Architectural and Urban Design of the Building of the Republic Institute for the Protection of Cultural-Historical and Natural Heritage."

These design assignments are formulated to encourage students to respond architecturally to the character of the theme and project brief. The focus is on identifying architectural expressions aligned with institutional, representative, or research frameworks, in accordance with the level of design competencies expected at this stage of study.

In addition to administrative spaces, accompanying programs such as exhibition, conference, and specialized research spaces, as well as hospitality and logistics facilities, have been integrated, allowing students to engage with a broad spectrum of design challenges. This approach is particularly important given the limited opportunities for practical application and the need to cultivate a diverse set of competencies.

The strategic selection of locations is essential for the depth and quality of design analysis. Sites located in transitional zones — between built and natural environments, historical and contemporary contexts, private and public domains — provide students with the opportunity to observe and interpret architectural context in a multilayered manner. Such an approach fosters the development of skills to analyze physical, social, and symbolic aspects of space, as well as sensitivity to place, which is considered a key component of responsible architectural education (Milić Aleksić, 2022).



a)



b)

Figure 1a. Display of conceptual models as tools for research and generation of information and ideas in the early phase of the design process (Module 1: Colloquium 1).

Figure 1b. Public presentation of students and presentation of the initial idea through graphic materials. All instructors participate in commenting and guide each student individually toward further project development (Module 1: Colloquium 1), Studio Project 7, academic year 2024/25.

According to the course syllabus, Design Studio 7 was conducted through lectures and practical exercises. At the beginning of the semester, students were introduced to the course structure and objectives, the implementation process, the project brief, forms and deadlines for submissions, as well as the grading criteria.

The practical part of the course (exercises) was organized into three modules, representing the three fundamental phases of the design process, each defined by specific goals, learning outcomes, and precise tools — both analog (sketches, working conceptual-research and presentation models) and digital (graphic documentation ranging from urban plans to details and 3D building models):

- **Module 1: From program and site analysis to spatial concept**
This phase encompassed initial analyses and research, culminating in design review 1, conducted as a digital presentation of the spatial concept through drawings and conceptual-research models (Figures 1a, b).
- **Module 2: From concept to architectural assembly**
This stage involved the arrangement of programmatic and spatial contents aligned with the formal models developed in the previous module, as well as elaboration of the building's function and structural logic.
- **Module 3: From architectural assembly to materialization**
This final phase included further project development and detailing, finalization of the design concept, and preparation of the final graphic materials. The process concluded with the submission of the semester elaboration in the form of a complete conceptual design. Special emphasis was placed on integrating spatial conception, structural systems, and materialization to ensure the project formed an architecturally coherent whole (Figure 2).

At the end of each module, a submission (design review) was required to evaluate the ongoing work throughout the semester, alongside the final result at the semester's conclusion. Each design review also included feedback from instructors and collaborators, aimed at guiding the student's further development.

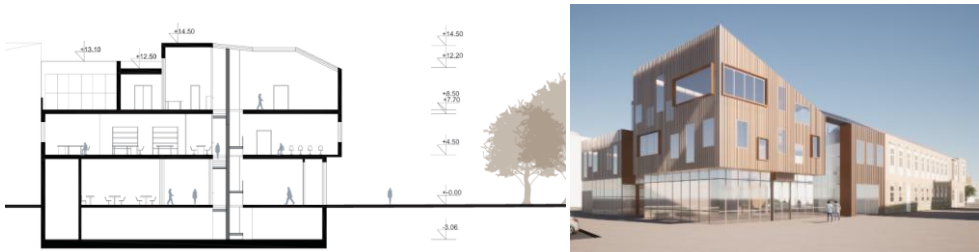


Figure 2. Final graphic attachments of the semester elaboration (Module 3: Colloquium 3) – cross-section and three-dimensional model of the building, within the assignment “Conceptual architectural and urban design of the building of the Republic Institute for the Protection of Cultural, Historical and Natural Heritage.” At this stage, students aimed to consistently translate their concepts into architectural solutions that are meaningfully and formally integrated into the existing urban fabric, respecting the spatial, cultural, and contextual specificities of the site. (Illustrations by student Jovana Đurđević, Studio Project 7, academic year 2023/24)

The exam format was conducted in the form of a public defense. Students briefly presented their work to peers and mentors, focusing on the spatial concept, with particular attention to volumetry, spatial character, and the relationship with the surrounding environment. The post-production for the public defense consisted of posters and a final model, which provided the audience with insight into the entirety of the conceptual and spatial solution (Figures 3a, b).

Within Design Studio 7 special attention was given to balancing digital and analog tools, with an emphasis on the model as a crucial element of the design process. From the very beginning, conceptual models were used as a means of exploration and initial spatial articulation in response to the given design problem. They served both as a medium for generating ideas and spatial relationships, and as a tool for analyzing context and programmatic requirements. Throughout the process, through iterative research and development models, the project was shaped and refined in accordance with the set objectives. The final models created by the students in the concluding phase represent a synthesis of the architectural idea. Through clear spatial articulation, structure,

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and materialization, the representative model provided the audience with insight into the final solution and the logic of its design (Figures 3a, b).



Figure 3a. Exam: students' final models as the result of the concluding phase of the design process.

Figure 3b. Exam: public presentation of the conceptual design with the final model and poster as a form of post-production, Studio Project 7, academic year 2024/25.

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RESULTS

In architectural design education, a key challenge lies in balancing the constraints of a formal curriculum with the need for flexible and development-oriented educational approaches. The analysis of teaching practice at the Faculty of Architecture, Civil Engineering and Geodesy at the University of Banja Luka suggests that a carefully designed design studio can serve as a potential foundation for a transformative learning experience, provided it encompasses two interrelated sets of elements:

- (1) curriculum adaptability to the pedagogical context, and
- (2) the methodological structure and dynamics of the teaching process.

(1) Curriculum and the Need for Adaptability

The case study, based on qualitative analysis of teaching documents and observation of the actual teaching process, points to several key factors influencing teaching effectiveness: realistic assessment of students' design abilities, continuity in the development of themes, a limited number of studio projects as an important pedagogical resource, and the application of interannual diversity as a strategy for teaching improvement.

Pedagogical influence vectors affecting the organization of architectural design teaching:

➤ **Current assessment of students' design abilities**

Design tasks within studio projects must align with the actual state of students' knowledge, skills, and independence at the time of instruction. This includes formative assessment of their competencies, not only technical (e.g., visualization, structural thinking, or spatial articulation) but also cognitive—critical thinking, capacity for contextual interpretation, and ability for independent conceptualization. Accordingly, projects must “grow with the students,” demanding more only after foundational skills have been established.

➤ **Scope and type of previous studio project themes**

Analysis of the sequence of previous studios allows instructors to formulate assignments that do not replicate already covered typologies and themes but rather build meaningfully on them. For example, if earlier study phases focused on residential programs, subsequent studio projects should ideally introduce more complex programmatic requirements—public facilities, hybrid structures, public spaces, and their role in shaping the urban fabric. Such thematic diversity fosters adaptability in students and enables the application of acquired knowledge in various spatial and programmatic contexts.

➤ **Limited number of studio projects and broad spectrum of competencies**

Given the limited number of studio projects throughout undergraduate studies (usually 6–8), each project must be carefully designed to encompass not only typology but also the development of multiple skills: formal articulation, functional organization, contextual analysis, programmatic complexity, spatial logic, and ethical relationships with the environment. The choice of location plays a special role here, with microlocations exhibiting pronounced spatial, cultural, and social layers offering significant potential for developing students' analytical and conceptual competencies.

➤ **Interannual diversity as a pedagogical strategy**

Over multiple years, the teaching staff gradually builds an internal pedagogical base through variation in themes, locations, and methods. This “interannual diversity” enables continuous testing of different approaches, which can later be transferred to other courses or cohorts. Diversity is especially important in smaller academic communities where instructors work with several generations simultaneously or consecutively. It represents a tool for pedagogical innovation and prevents stagnation of teaching practice.

(2) Methodological Structure and Dynamics of the Teaching Process

Results indicate that an added value in improving the design process was brought by a teaching structure based on the alternating use of analog and digital tools. This combination fosters not only the technical and graphic literacy of students but also the development of critical thinking through comparative analysis of different media of expression (Oxman, 2008). Furthermore, active collaboration between students and instructors, as well as periodic collective critiques and final public presentations, proved to be essential in forming a study culture of mutual learning (peer learning), knowledge transfer, and building confidence in publicly presenting ideas (Schön, 1987; Nicol & Pilling, 2000).

DISCUSSION

The results suggest that meaningful progress in the design studio is closely related to how design tasks are conceptually and pedagogically structured. Carefully formulated tasks, aligned with students' actual levels of knowledge and skills, significantly support the development of critical thinking, creativity, and independent problem-solving in architectural design. These findings are consistent with previous research in design studio pedagogy, which highlights the

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importance of gradually introducing complexity and contextual considerations (Schön, 1987; Oxman, 2008).

Integrating various aspects of design — from spatial analysis and conceptualization to technical development and public presentation — supported by the alternating use of analog and digital tools, enables the development of comprehensive competencies. This approach not only strengthens students' graphic and technical literacy but also fosters their ability to interpret space across multiple layers and make well-founded design decisions.

The discussion further emphasizes the pivotal role of the teaching team in structuring a clear, logical, and motivating sequence of tasks, and in adapting pedagogical strategies to different student cohorts. Instructors' adaptability — in selecting themes, sites, and methodological approaches — is key to ensuring the continuous improvement of the design studio process and maintaining pedagogical relevance in the contemporary educational context.

CONCLUSION

This study has highlighted the theoretical importance of the design studio in architectural education and analyzed practical outcomes within the studio at the Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka. The findings indicate that the quality of teaching relies on the faculty's ability to recognize students' actual capabilities, organize thematic modules effectively, and continuously adapt pedagogical methods to the needs of each generation.

A clearly defined and adaptive curriculum, combined with a strategically planned methodological approach, not only promotes the development of analytical, conceptual, and presentation skills but also prepares students for professional practice. The integration of curricular and methodological elements facilitates the continuous improvement of the teaching process and ensures the program's pedagogical relevance in the contemporary context of architectural education.

While this research does not exhaust all possible avenues for enhancing design studio teaching, it provides a solid foundation for future studies and the development of pedagogical practices that can contribute to the ongoing advancement of architectural education for emerging professionals.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper

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IMPLEMENTATION OF A PASSIVE RC LOW-PASS FILTER FOR EMBEDDED IOT SYSTEMS WITH OPEN-SOURCE SIMULATION SUPPORT

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ABSTRACT

In this study, we explore the design, simulation, and deployment of a passive RC low-pass filter, specifically targeting its integration within Internet of Things (IoT) applications. We employed a symbolic computing environment to theoretically model the filter's frequency response, analytically deriving the transfer function and numerically validating it through simulation. Experimental verification was conducted using a virtual prototyping platform, where the filter was tested with various input signals. As a practical demonstration, the filter was implemented within a Python-based simulation of an IoT node, emulating a microcontroller setup for capturing analog signals with additive noise. The real-time processing of filtered outputs validated the filter's capacity to diminish high-frequency noise prior to digital conversion. This study highlights the ongoing importance of analog filtering techniques in enhancing data accuracy in contemporary IoT systems.

Keywords: RC low-pass filter, Internet of Things, numerical optimization.

INTRODUCTION

The IoT has transformed the way data is acquired, transmitted, and processed across numerous domains, from smart homes to industrial automation and environmental monitoring. At the core of these systems are sensor nodes that often operate under strict energy, size, and cost constraints. Despite the growing role of digital signal processing in embedded applications, analog signal conditioning remains a vital first step, particularly when high-frequency noise threatens to degrade the accuracy of analog-to-digital conversion. In such contexts, low-pass filters are usually employed to attenuate undesirable high-frequency components before digitization. By doing so, they help preserve the integrity of the measured signal and prevent aliasing. This is especially important in low-power devices where computational resources are limited, and software-based filtering is either infeasible or insufficient. Analog filtering, therefore, complements digital processing and plays an important role in maintaining data quality in IoT environments.

Recent studies have addressed the challenges of designing analog filters suitable for embedded systems. For example, authors in (Yuan et al., 2024) proposed an active RC low-pass and band-pass filter with automatic frequency tuning, enabling dynamic reconfiguration between Wi-Fi (Wireless Fidelity) and BLE (Bluetooth Low Energy) modes. Their work highlights the importance of tunability and integration in modern baseband circuits. In parallel, (Liao et al., 2022) developed a virtual low-pass filter for wind energy systems, where the filter was integrated into a power control loop to smooth output fluctuations without requiring physical filtering components. Both approaches illustrate how low-pass filtering, whether physical or emulated, can enhance system stability and performance across very different domains. Beyond active-RC designs, other analog filter topologies have also been investigated. For example, Gm-C filters, which rely on transconductance elements rather than discrete resistors, offer advantages in terms of compactness and bandwidth. However, they typically suffer from limited linearity and sensitivity to process variations, especially at low supply voltages (Ding et al., 2012). As a result, active-RC filters are

often preferred in precision applications due to their improved noise and linearity characteristics. While such architectures are essential in high-performance systems, they may be unnecessary in simpler sensing tasks. In many IoT applications, where fixed bandwidth and low energy consumption are sufficient, passive RC low-pass filters offer a practical and efficient solution. Their minimal component count, predictable behavior, and ease of integration make them particularly attractive for early-stage signal conditioning. Motivated by this, the present study focuses on the design and simulation of a passive RC low-pass filter for use in IoT sensor nodes. The analysis combines symbolic modeling of the filter's frequency response with numerical simulations in Python. To complement the theoretical findings, a virtual prototyping environment is used to visualize the filter's behavior in time and frequency domains. Finally, the filter's performance is evaluated in a simulated IoT scenario, where it is applied to a noisy analog signal prior to digital conversion. Through this workflow, we aim to demonstrate that passive analog filtering remains highly relevant in contemporary embedded systems, not only due to its simplicity but also because of its measurable contribution to signal fidelity.

The remainder of this paper is organized as follows. Section 2 presents the theoretical foundation of the RC low-pass filter, including derivation of its transfer function and analysis of its frequency-domain behavior. Section 3 describes the numerical implementation and simulation results obtained using Python, with particular attention to signal smoothing in a simulated noisy environment. In Section 4, we introduce a virtual experimental setup developed in NI Multisim to visualize and validate the filter's behavior under different input conditions. Section 5 explores the integration of the filter into a Python-based IoT simulation framework, emulating real-world sensor data and analog preprocessing. Finally, Section 6 discusses the results, highlights the benefits and limitations of passive filtering in embedded applications, and outlines potential directions for future research.

THEORETICAL FRAMEWORK

A passive RC low-pass filter is a canonical example of a first-order linear time-invariant system, widely used for analogue signal conditioning. It consists of a resistor, R , in series with a capacitor C , where the output voltage, v_{out} , is taken across the capacitor. This configuration, presented in Fig. 1, suppresses high-frequency components of the input signal, v_{in} , while allowing low-frequency components to pass through with minimal attenuation (Li et al., 2017).

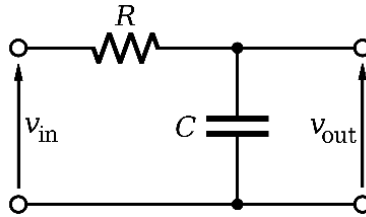


Figure 1. Schematic representation of a first order RC low-pass filter. The input voltage v_{in} is applied across the series combination of resistor R and capacitor C , with the output voltage v_{out} measured across the capacitor.

The behavior of the circuit presented in Fig. 1 is governed by Kirchhoff's voltage law (Coppens, et al., 2017):

$$v_{in}(t) = v_R(t) + v_C(t) \quad (1)$$

where the voltage drop across the resistor is given by Ohm's law as $v_R(t) = Ri(t)$, and the voltage across the capacitor relates to current by the integral relation $v_C(t) = \frac{1}{C} \int i(t)dt$.

Using these expressions, we obtain the governing differential equation:

$$v_{in}(t) = RC \frac{dv_{out}(t)}{dt} + v_{out}(t) \quad (2)$$

To analyze the system in the frequency domain, we apply the Laplace transform to Eq. (2). This transformation requires assumptions about the system's initial state. For a passive filter that has not yet been energized, it is physically justified to assume that the capacitor is uncharged at $t = 0$. This implies: $v_{out}(t = 0) = 0$. With this initial condition, the Laplace transform of the derivative becomes: $\mathcal{L}[dv_{out}(t)/dt] = s v_{out}(s)$. Applying the transform to Eq. (2) yields the algebraic relation:

$$v_{in}(s) = (sRC + 1)v_{out}(s) \quad (3)$$

from which we obtain the transfer function:

$$H(s) = \frac{v_{out}(s)}{v_{in}(s)} = \frac{1}{1+sRC} \quad (4)$$

This parameter characterizes the system's response to sinusoidal excitation across all frequencies. For a steady-state sinusoidal input, we substitute $s = j\omega$ to obtain the frequency response:

$$H(j\omega) = \frac{1}{1+j\omega RC} \quad (5)$$

The magnitude and phase of this complex function are given by:

$$|H(j\omega)| = \frac{1}{\sqrt{1+(\omega RC)^2}}, \quad \angle H(j\omega) = -\tan^{-1}[\omega RC] \quad (6)$$

These expressions describe how the filter attenuates signals of different frequencies. At low frequencies $\omega \ll 1/RC$, the gain tends toward unity and the phase shift approaches zero. Conversely, at high frequencies $\omega \gg 1/RC$, the gain decreases proportionally to $1/\omega$, and the phase shift approaches $-\pi/2$.

The transition point between the passband and attenuation region is known as the cutoff angular frequency:

$$\omega_C = \frac{1}{RC} \quad (7)$$

which corresponds to a frequency:

$$f_C = \frac{1}{2\pi RC} \quad (8)$$

At this frequency, the magnitude drops to $-1/\sqrt{2} \approx 0.707$, corresponding to a power reduction of 50% or -3 dB. For applications involving signal analysis and logarithmic visualization, it is convenient to express the gain in decibels:

$$|H(j\omega)|_{dB} = -10 \log_{10}(1 + (\omega RC)^2) \quad (9)$$

The slope of the Bode magnitude plot (see Section 3) asymptotically approaches -20 dB/decade beyond the cutoff frequency, which is consistent with the first-order nature of the filter. The phase response similarly transitions from 0 to -90° , with the inflection point occurring at $\omega = \omega_C$. This mathematical formulation provides a complete frequency-domain description of the RC low-pass filter. It serves as the analytical foundation for the numerical simulations and virtual prototyping to be discussed in the following sections.

NUMERICAL SIMULATION IN PYTHON

To assess the theoretical model under controlled conditions and to explore the RC filter's performance in typical IoT-like scenarios, we carried out a numerical simulation using Python. This enables us to track how the filter suppresses high-frequency noise and preserves the structure of low-frequency signals. Moreover, this method provides insight into signal behaviour prior to any physical implementation, which is particularly useful when designing embedded systems where testing is often constrained. Such numerical evaluations are frequently applied during early-stage development of sensor interfaces, especially in low-power systems where analogue preprocessing is tightly coupled with digital acquisition and conversion stages.

The simulation relies on a discrete-time formulation of the Eq. (2), derived in Section 2. Using a backward Euler approximation (Yeh et al., 2007), the system is represented by the recursive expression:

$$v_{out}[n] = v_{out}[n-1] + \alpha(v_{in}[n] - v_{out}[n-1]). \quad (10)$$

with $\alpha = \Delta t / (RC + \Delta t)$, where Δt is the simulation time step. This relation imitates the dynamic behavior of the analog circuit and is numerically stable, making it suitable for digital implementation on microcontrollers. A synthetic input signal was constructed as the sum of a 5 Hz sine wave and additive white Gaussian noise, representing a simplified model of analogue sensor output contaminated by environmental interference. The filter was applied to this signal using the recursive relation (see Eq. (10)). As shown in Fig. 2, the output signal maintains the underlying structure of the sinusoid while significantly reducing high-frequency fluctuations.

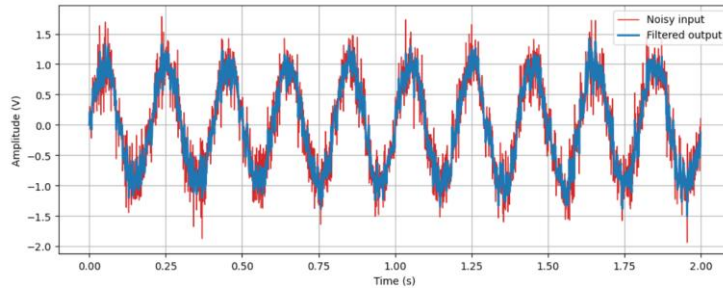


Figure 2. Simulated input (red) and filtered output (blue) in the time domain.

To quantify the effect of filtering, the signal-to-noise ratio (SNR) was calculated before and after applying the filter. The SNR was defined as (Mittal et al., 2024):

$$SNR = 10 \log_{10} \left(\frac{\sigma_{signal}^2}{\sigma_{noise}^2} \right) \quad (11)$$

where σ_{signal}^2 and σ_{noise}^2 denote the variances of the clean signal and noise, respectively. In our simulation, as shown in Fig.3, the initial SNR was approximately 7.68 dB, while the filtered output reached 12.34 dB, indicating a notable improvement in signal clarity.

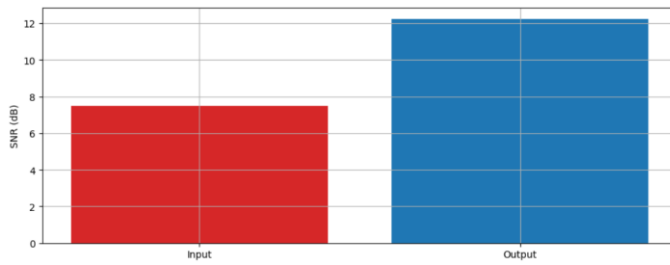


Figure 3. Signal-to-noise ratio before and after filtering.

To verify the frequency-domain behaviour of the RC low-pass filter, the magnitude response was first computed using the analytical expression given by Eq. (9). This function describes the gain in decibels as a function of angular frequency and reveals the characteristic profile of a first-order low-pass filter (Aye and Hla, 2025): constant gain at low frequencies and attenuation beyond the cutoff point.

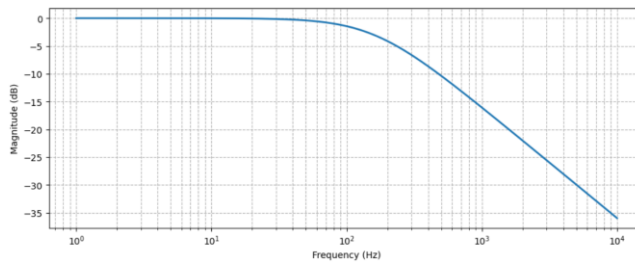


Figure 4. Theoretical Bode magnitude plot of the RC low-pass filter.

Fig. 4 shows the corresponding magnitude response obtained through numerical simulation of the discrete-time implementation. The curve exhibits a flat passband region followed by a smooth roll-off at higher frequencies, in line with the expected -20 dB per decade slope. This confirms that the discrete-time filter preserves the essential frequency-selective properties of its continuous counterpart, making it suitable for noise suppression in embedded signal acquisition systems.

VIRTUAL PROTOTYPING IN NI MULTISIM

To complement the analytical and numerical analyses, a virtual prototype of the RC low-pass filter was constructed in NI Multisim. This environment allows for realistic circuit simulation based on SPICE models and provides tools for both time-domain and frequency-domain evaluation. The objective was to replicate the filter behaviour under conditions that closely resemble hardware implementation, using the same component values adopted in previous sections ($R = 1 \text{ k}\Omega$, $C = 1 \text{ }\mu\text{F}$). Unlike the Python simulation in Section 3, which incorporated synthetic noise to model sensor-level disturbances, the Multisim simulations focus exclusively on the behaviour of the circuit. By removing noise, we isolate the effect of the filter components and better visualize how signal characteristics change solely due to variations in capacitance. The schematic used in the simulation is shown in Fig. 5. A 5 Hz sine wave of 1 V is applied to the RC network using a function generator (XFG1). The output is observed across the capacitor using a virtual oscilloscope (XSC1).

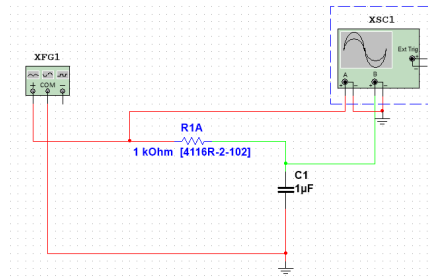


Figure 5. Schematic of the RC low-pass filter simulated in NI Multisim ($R = 1 \text{ k}\Omega$, $C = 1 \text{ }\mu\text{F}$).

The measured input and output waveforms for two capacitance values are shown in Fig. 6. With $C = 1 \text{ }\mu\text{F}$, the output signal (green trace) closely follows the input (red trace), with minor attenuation and a small phase lag. This behavior is consistent with the fact that the input frequency (5 Hz) is much lower than the cutoff frequency of the filter, $f_c = 1/2\pi RC \approx 159 \text{ Hz}$, so most of the signal passes through unaltered. When the capacitance is increased to $10 \text{ }\mu\text{F}$, the cutoff frequency drops to approximately 15.9 Hz. Although the input frequency remains the same, it is now closer to the filter's corner frequency. As a result, the circuit responds more gradually: the output becomes smoother, attenuated, and increasingly delayed in phase. Physically, this reflects the greater energy storage capacity of the larger capacitor, which charges and discharges more slowly, effectively dampening rapid voltage changes.

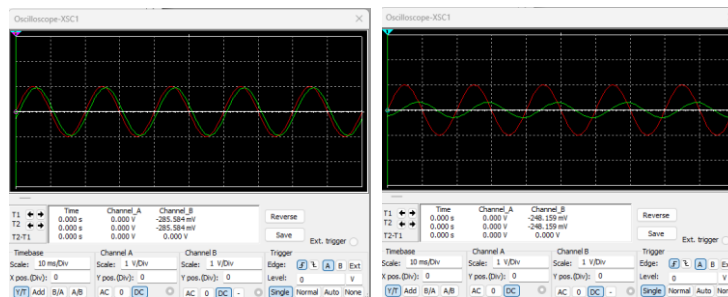


Figure 6. Comparison of time-domain responses for $C = 1 \text{ }\mu\text{F}$ (left) and $C = 10 \text{ }\mu\text{F}$ (right). Increasing capacitance introduces stronger attenuation and phase lag, reflecting the slower charging dynamics of the capacitor.

The results presented in Fig. 6 highlight a fundamental trade-off in RC filtering: increasing capacitance enhances noise suppression and signal smoothing but also introduces a delay and attenuates even low-frequency components if the cutoff becomes too low.

To analyse the frequency response, we used Multisim's Bode plot tool. Fig. 7 shows the magnitude plots for both configurations. The classic first-order roll-off of -20 dB/decade is evident in both cases, with a clear shift of the cutoff frequency when C increases. This confirms that the filter's bandwidth is inversely proportional to the RC product and that tuning C enables flexible control over the signal passband.

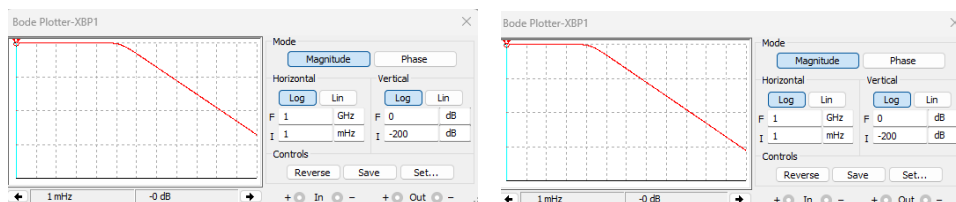


Figure 7. Bode magnitude plots for $C = 1 \text{ }\mu\text{F}$ (left) and $C = 10 \text{ }\mu\text{F}$ (right). Higher capacitance lowers the cutoff frequency, narrowing the filter's bandwidth.

Together, the simulations presented in this section demonstrate how passive RC filters shape the temporal and spectral characteristics of signals. Even in idealized conditions, the observed behaviours align well with theoretical predictions and provide a useful foundation for implementing such filters in real-world analog or embedded systems.

INTEGRATION INTO PYTHON-BASED IOT SIMULATION FRAMEWORK

Following the theoretical, numerical, and virtual analyses presented in previous sections, we now turn to a practical scenario in which the RC low-pass filter is integrated into a simulated IoT sensor node. While Section 3 explored the filter's numerical behaviour using synthetic signals and Section 4 offered a component-level perspective through virtual prototyping in NI Multisim, this section bridges the gap between simulation and application by emulating a simplified embedded sensing system.

In this section, we recreate a situation common in real-world IoT deployments: a sensor provides continuous analog readings of a slowly varying physical quantity, such as temperature or pressure, which are then contaminated by environmental or electronic noise. Before this signal can be digitized and processed, analog filtering is typically employed to reduce high-frequency interference that could compromise measurement accuracy or exceed the ADC's bandwidth. To realistically model this process, the clean sinusoidal signal obtained in Section 4 via Multisim was adopted as the true reference signal, the ideal physical variable we aim to measure. Gaussian noise was numerically added to simulate the distortions encountered in real-world sensing. The resulting signal thus mimics a corrupted analog input to a microcontroller. This noisy waveform was then passed through the recursive digital filter implemented in Section 3, using the same values for resistance and capacitance ($R = 1\text{ k}\Omega$, $C = 1\text{ }\mu\text{F}$), ensuring direct comparability with earlier results. The outcome of this simulation is shown in Fig. 8. The red curve represents the noisy signal, whose high-frequency fluctuations obscure the true dynamics of the underlying physical quantity. The black dashed line corresponds to the original, noise-free signal reused from the virtual experiment in Multisim. The blue curve shows the output of the filtering process. It is evident that the filtered signal follows the slow variations of the original waveform, while the fast oscillations are effectively suppressed. This confirms the filter's ability to enhance signal quality by isolating relevant low-frequency components and rejecting high-frequency noise.

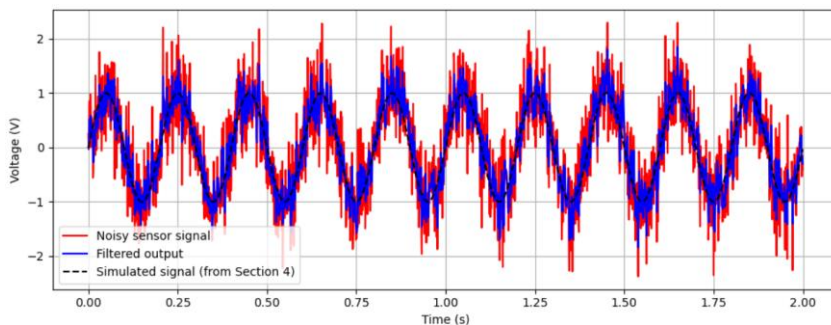


Figure 8. Simulated sensor acquisition in a Python-based IoT node. The red curve represents a noisy input signal. The blue curve is the filtered output using the RC low-pass filter. The black dashed line denotes the original signal waveform extracted from the Multisim simulation in Section 4.

The result presented in Fig. 8 confirms the low-pass behavior of the RC filter. The signal components at low frequencies (around 5 Hz in this case) are transmitted almost undistorted, while rapid fluctuations introduced by noise (which span a broad frequency range) are heavily attenuated. This selectivity stems from the fact that the capacitor's reactance decreases with frequency, shunting high-frequency components away from the output node. As a result, the filter's output predominantly consists of the frequency components within the passband, with minimal contribution from higher frequencies. This experiment reinforces the practical utility of analog

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filtering in IoT systems. Even in the presence of significant noise, a simple first-order RC circuit provides meaningful improvement in signal clarity without requiring additional digital resources or power. The filtering operation is local, passive, and computationally free making it ideal for constrained edge devices. Furthermore, by using the same reference waveform as in Multisim simulations, we verify that the filter's performance translates consistently across different implementation layers, from physical hardware to software reproduction.

CONCLUSIONS

This paper explored the behavior and practical utility of a passive RC low-pass filter across theoretical, numerical, and simulated environments. Starting from the differential equation model, we derived the filter's transfer function and described its response in both time and frequency domains. Python-based simulations showed that the filter significantly improves signal clarity by attenuating high-frequency noise. These results were consistent with the expected -20 dB per decade roll-off and the preservation of low-frequency content. The filter was then implemented in a virtual NI Multisim environment, using identical component values. The comparison between different capacitances illustrates how increasing capacitance lowers the cutoff frequency, enhancing filtering while introducing more delays. These trends aligned well with analytical predictions and offered insight into real-world circuit behavior. Finally, we integrated the filter into a simplified IoT simulation. A noisy sensor signal was passed through the RC circuit before digitization. The output confirmed that analog filtering remains a valuable preprocessing step, particularly for low-power systems where digital resources are limited. By using the same reference waveform throughout all stages, we ensured consistency across theory, simulation, and practical modeling. In summary, even a simple passive filter can provide meaningful improvements in signal quality. Its predictable behavior, low cost, and zero computational load make it well suited for embedded and IoT applications. Future work could involve physical implementation on microcontrollers, exploration of adaptive filter tuning, or extension to higher-order analog networks.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper

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SIMULATION OF ULTRAFAST FREE ELECTRON DYNAMICS AND TIME-DEPENDENT REFLECTIVITY IN SKIN-LIKE TISSUE MEDIA UNDER SHORTPULSE LASER EXCITATION

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ABSTRACT

In this study, we investigate the ultrafast dynamics of free electrons in skin-like tissue media, stimulated by laser pulses with durations between 50 fs and 100 fs. Our analysis is based on a rate-equation approach for the evolution of free electron density $N_e(t)$ under different laser pulse durations. The simulated electron densities are then used to calculate the time-dependent change in reflectivity, $\Delta R(t)$, via a Drude-based dielectric function model and Fresnel equations for normal incidence. This enables us to assess the transient optical properties of tissue equivalents during and after ultrafast electronic excitation. The results highlight characteristic thresholds for carrier generation and show how pulse parameters influence the magnitude and temporal profile of $\Delta R(t)$. The presented approach offers a framework for understanding and predicting ultrafast reflectivity changes in tissue-like media, which can be useful for laser-based diagnostics, ultrafast imaging, and controlled photothermal treatments.

Keywords: free electron dynamics, skin-like tissue media.

INTRODUCTION

Ultrafast laser pulses have become an essential tool for exploring light-matter interactions in biological and tissue-like media. In the femtosecond to picosecond regime, this interaction is governed by nonlinear absorption mechanisms, including multiphoton ionization (MPI), tunneling ionization (TI), and subsequent avalanche ionization (AI), which lead to the rapid generation of free carriers before significant thermal or mechanical effects take place. Such processes occur on timescales much shorter than those of heat diffusion or stress wave propagation, enabling selective interaction with the target medium. This timescale separation enables high-precision material modification with minimal collateral damage, making ultrafast lasers valuable for biomedical imaging, microsurgery, and non-invasive diagnostics (Stuart et al., 1996; Vogel et al., 2005; Tirlapur and König, 2002). Understanding the underlying electron dynamics in these conditions provides the physical basis for interpreting time-resolved measurements and optimizing laser-based medical techniques.

Previous studies have developed both experimental and theoretical frameworks to characterize free carrier generation and its optical consequences. On the experimental side, time-resolved pump-probe reflectivity and transmission measurements have been used to analyze femtosecond-scale changes in refractive index and absorption, revealing distinct thresholds for carrier generation and transient reflectivity changes (Vogel et al., 2008; Krüger et al., 2020). These measurements not only map the ultrafast temporal evolution of the material response but also serve as basis for validating theoretical predictions. On the modeling side, rate-equation approaches have been widely adopted to describe the temporal evolution of free electron density $N_e(t)$, typically incorporating MPI and AI terms, as well as recombination processes (Rethfeld, 2004; Qiu et al., 2014). The flexibility of these models allows researchers to investigate a wide range of pulse durations, wavelengths, and fluences without requiring immediate experimental realization. These

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models, coupled with dielectric function formalisms such as the Drude model, allow the computation of time-dependent optical properties, including the reflectivity change $\Delta R(t)$. In biological media such as skin, this approach has proven effective in linking microscopic electronic processes with macroscopic optical responses, providing a pathway toward quantitative interpretation of ultrafast laser-tissue interaction data.

In this work, we numerically investigate the ultrafast generation and evolution of free electrons in skin-like tissue equivalents excited by laser pulses of durations between 50 fs and 100 fs ($1\text{fs} = 1 \times 10^{-15}\text{s}$). We use a rate-equation model to calculate $N_e(t)$ for different pulse durations and then determine $\Delta R(t)$ using a Drude-based dielectric function in combination with Fresnel equations at normal incidence. By systematically varying the excitation parameters, we identify correlations between the laser pulse characteristics and the temporal evolution of the transient optical response. This allows us to identify characteristic thresholds for carrier generation and to examine how laser pulse duration influences both the magnitude and temporal evolution of the transient reflectivity signal. The developed approach provides insight into the correlation between excitation conditions and the resulting ultrafast optical response of tissue-like media.

The remainder of this paper is organized as follows. Section 2 describes the theoretical framework, including the rate-equation model for free electron generation and the optical model used for calculating transient reflectivity. Section 3 reports and discusses simulation results, focusing on the dependence of $N_e(t)$ and $\Delta R(t)$ on pulse duration, fluence, and wavelength. Section 4 summarizes the key findings presented in this study.

THEORETICAL FRAMEWORK

When an ultrashort laser pulse impinges on a skin-like tissue model, the very first physical consequence is the rapid generation of free carriers within the material. This process takes place on a sub-picosecond timescale, well before any significant heat conduction or mechanical stress relaxation can occur. At such ultrafast temporal scales, electronic excitation dynamics dominate over thermal or structural changes. The primary mechanisms responsible for the formation of conduction-band electrons are photoionization and AI. These processes act in concert to determine the instantaneous free-electron density $N_e(t)$, a quantity that critically influences the optical response of the medium during and after the laser-matter interaction (Couairon and Mysyrowicz, 2007; Stuart et al., 1996). For this purpose, the skin-like tissue medium is modelled using optical and electronic parameters representative of hydrated biological and water-based materials, as reported in (Vogel et al. (2005), Qiu et al. (2014), and Krüger et al. (2020)).

The initiation of ionization is governed by photoionization, which in general may proceed via MPI or TI. Under the irradiation conditions considered here (near-infrared femtosecond pulses at moderate intensities) the interaction is well described within the multiphoton picture, and TI contributions can be neglected. In the MPI regime, a bound electron simultaneously absorbs an integer number K of photons, such that the total absorbed photon energy exceeds not only the material's bandgap E_g , but also the ponderomotive potential U_p , which represents the cycle-averaged quiver energy of a free electron in the laser field. The smallest such integer is:

$$K = \left\langle \frac{E_g + U_p}{\hbar\omega} \right\rangle \quad (1)$$

where ω is the laser angular frequency. The ponderomotive potential is given by:

$$U_p = \frac{e^2 E^2}{4m\omega^2} \text{ or } U_p [\text{eV}] \approx 9.33 \times 10^{-14} I [\text{W}/\text{cm}^2] \lambda^2 [\mu\text{m}^2] \quad (2)$$

and represents the cycle-averaged quiver energy of a free electron in the oscillating electric field of the laser. It depends on the elementary charge e , the electron rest mass m , the peak electric field

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amplitude E , the instantaneous laser intensity I , and the laser wavelength λ . Physically, U_p increases with both the laser intensity and the square of the wavelength, reflecting the stronger and slower oscillations experienced by the electron in such conditions. At sufficiently high intensities, the effective ionization threshold becomes $E_g + U_p$, meaning that the electron must absorb enough photon energy to overcome not only the material bandgap E_g but also the additional energy associated with its oscillatory motion in the field. However, for moderate intensities where $U_p \ll E_g$, the ponderomotive contribution is negligible, and the minimum number of photons required for MPI reduces to $K = \langle E_g / \hbar \omega \rangle$.

Since the ponderomotive term, U_p , can effectively raise the ionization threshold, the overall probability of MPI is linked to the instantaneous laser intensity. This naturally leads to a description of the process in terms of an intensity-dependent ionization rate. The efficiency of MPI is strongly intensity-dependent and can be described by a power-law rate:

$$W_{MPI}(I) = \sigma_K I^K \quad (3)$$

Here, σ_K is the generalized K -photon absorption cross-section, a material-specific constant typically determined experimentally or from nonlinear optical theory (Reiss, 1992; Smith and Gallagher, 1988). Its value can vary by orders of magnitude depending on the material's structure, photon energy, and configuration (Couairon and Mysyrowicz, 2007; Denk et al., 1995; Delone and Krainov, 2000). In particular, multiphoton microscopy literature provides quantitative measurements of multiphoton cross-sections in biological tissues and fluorescing media, which helps anchor plausible values for tissue-like materials in modeling studies (Denk et al., 1995; Couairon and Mysyrowicz, 2007).

Once a seed population of conduction-band electrons is generated through MPI, further carrier multiplication can occur via AI. In this process, the existing free electrons absorb additional energy from the laser field between successive collisions with the lattice. If the acquired kinetic energy exceeds the impact-ionization threshold, typically close to the bandgap energy, these electrons can liberate additional bound electrons, initiating a collisional cascade. As a result, the free-electron density grows nonlinearly during the pulse, often leading to a rapid transition from a weakly ionized to a strongly ionized state. The avalanche growth rate is commonly modelled as:

$$W_{AI}(I, N_e) = \alpha(I) I N_e \quad (4)$$

where α is the avalanche coefficient, determined by the electron-phonon scattering rate, the mean free path, and the threshold energy for impact ionization (Stuart et al., 1996; Rethfeld et al., 2004).

In the present simulations, α was modeled as an intensity-dependent parameter, reflecting the fact that the efficiency of impact ionization increases with the instantaneous laser field strength. The dependence was expressed as: $\alpha(I) = \alpha_0 / I$, with $\alpha_0 = 5 \times 10^{10} \text{ s}^{-1}$. This is in accordance with reported values for skin-like tissue analogues (Rethfeld et al., 2004; Vogel et al., 2005). Such formulation provides a realistic scaling of the avalanche rate under femtosecond excitation and couples to the seed population generated by MPI, meaning that without the initial multiphoton-generated carriers, AI would not be initiated under the present irradiation conditions.

Once the seed electron population has been generated by MPI and subsequently amplified through AI, the time evolution of the free-electron density is governed by a competition between generation and loss mechanisms. While MPI acts as an ultrafast source term active primarily during the laser pulse, AI can continue to operate throughout the pulse duration, leading to exponential carrier

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multiplication. Simultaneously, recombination processes act to reduce the electron density once electrons are promoted to the conduction band. The interplay of these contributions can be expressed through the rate equation for the electron density:

$$\frac{dN_e}{dt} = W_{MPI}(I) + W_{AI}(I, N_e) - \frac{N_e}{\tau_r} \quad (5)$$

Here, the first term represents photoionization-induced seeding, the second term accounts for avalanche growth, and the last term describes electron recombination with an effective lifetime τ_r . This term incorporates both radiative and nonradiative recombination channels, and in biological or skin-like media it can range from a few to hundreds of picoseconds, depending on microscopic structure, defect density, and impurity levels (Vogel et al., 2005).

Since the laser pulse has a finite temporal envelope, the instantaneous intensity $I(t)$ must be explicitly accounted for in all rate expressions. For a transform-limited Gaussian pulse with full width at half maximum (FWHM) duration τ_p and peak intensity I_0 , the temporal profile is given by:

$$I(t) = I_0 \exp[-4 \ln 2 (\frac{t}{\tau_p})^2] \quad (6)$$

This functional form ensures that $I(t)$ correctly describes the rise and decay of the pulse around its temporal center. Because both MPI and AI rates scale with the instantaneous intensity, the temporal envelope directly governs the growth dynamics of $N_e(t)$ in simulations. In particular, for femtosecond-scale pulses, the sharp temporal localization of $I(t)$ means that most of the free-electron population is generated within only a few optical cycles near the peak of the pulse.

The temporal evolution of $N_e(t)$, governed by the coupled MPI and AI processes under the finite pulse envelope, is not just a theoretical framework. It directly determines how the material's optical properties change during and after the laser-matter interaction. In particular, the accumulation of free carriers alters the dielectric response of the medium on femtosecond timescales, leading to measurable changes in its reflectivity and transmission. To capture this effect quantitatively, we describe the optical response using the Drude free-electron model (Sokolowski-Tinten and von der Linde, 2000; Rethfeld et al., 2004):

$$\varepsilon(\omega, t) = \varepsilon_b(\omega) - \frac{N_e(t)e^2}{\varepsilon_0 m^*} \cdot \frac{1}{\omega^2 + i\gamma\omega} \quad (7)$$

where $\varepsilon_b(\omega)$ is the unperturbed dielectric constant, m^* is the effective electron mass, and γ is the electron collision frequency. At normal incidence, the reflectivity follows from the Fresnel formula:

$$R(t) = \left| \frac{\sqrt{\varepsilon(\omega, t)} - 1}{\sqrt{\varepsilon(\omega, t)} + 1} \right|^2 \quad (8)$$

The transient reflectivity change, a key observable in pump-probe experiments, is defined as (Sundaram and Mazur, 2002; Vogel et al., 2005):

$$\Delta R(t) = R(t) - R_0 \quad (9)$$

where R_0 denotes the reflectivity in the absence of the pump pulse. This quantity encodes the ultrafast dynamics of free-electron generation and decay, allowing direct comparison between simulations and experimental measurements. By coupling the ionization rate equations with the Drude optical model, we establish a predictive framework that links laser parameters (pulse duration and wavelength) to measurable optical signatures such as $\Delta R(t)$. This integrated approach forms the basis of our numerical simulations presented in the next section.

RESULTS AND DISSCUSION

In this section, we present numerical simulations of ultrafast free-carrier generation and its impact on the transient optical response of a skin-like medium under laser excitation. The results are obtained by solving the rate equations for MPI, AI, and carrier recombination (see Eq. (4)), using the Gaussian temporal envelope (Eq. (5)) of the incident laser pulse as described in the theoretical framework. The simulations are designed to reveal the interplay between the initial seeding of conduction-band electrons through MPI, their subsequent multiplication via AI, and their decay through recombination channels. By tracking the full temporal evolution of the free-electron density $N_e(t)$ for different pulse durations, we can identify the dominant processes governing carrier dynamics on sub-picosecond timescales. These carrier populations are then coupled to the Drude optical model to calculate the transient reflectivity change $\Delta R(t)$, which serves as a direct observable for comparison with ultrafast pump-probe experiments (Vogel et al., 2005; Stuart et al., 1996; Rethfeld et al., 2004; Sundaram and Mazur, 2002).

Fig. 1 presents the simulated temporal evolution of the free-electron density in a skin-like medium for two different femtosecond pulse durations: 50 fs and 100 fs, at identical peak intensity $I_0 = 1 \times 10^{14} \text{ W/cm}^2$. The simulation shown here corresponds to the MPI-only regime, where AI and recombination are initially neglected in order to isolate the seeding stage of free-carrier generation.

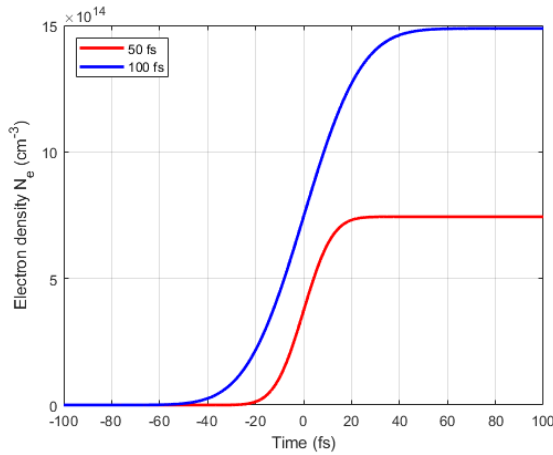


Figure 1. Temporal evolution of the free-electron density $N_e(t)$ in a skin-like medium for Gaussian laser pulses with durations of 50 fs (red) and 100 fs (blue) at the same peak intensity, $I_0 = 1 \times 10^{14} \text{ W/cm}^2$ including MPI.

The growth of $N_e(t)$ in Fig. 1 follows the temporal structure of the laser intensity envelope, but the magnitude of the final densities is dictated by how long the material remains under conditions favorable for MPI. Multiphoton ionization is a high-order non-linear process in which the instantaneous ionization rate depends steeply on the laser intensity, I , scaling as $W_{MPI} \propto I^K$,

where K is the number of photons required to cross the bandgap. This dependence means that significant ionization occurs only in the central part of the pulse where $I(t)$ approaches its maximum. For the shorter, 50-fs pulse, the high-intensity window is extremely narrow. The field amplitude rises and falls rapidly, and although the instantaneous rate W_{MPI} reaches the same peak value as in the 100-fs case, the available time for sustained ionization is short. As a result, the integrated number of photon-absorption events per atom is smaller, and the final free-electron density is correspondingly reduced. For the 100-fs pulse, the broader temporal envelope keeps the intensity above the multiphoton threshold for roughly twice as long, effectively increasing the “interaction time” during which MPI can proceed efficiently. This difference directly translates into a greater cumulative electron yield. Quantitatively, the final simulated values are: $N_{e,final}^{50fs} \approx 7.44 \times 10^{14} cm^{-3}$ and $N_{e,final}^{100fs} \approx 1.49 \times 10^{15} cm^{-3}$. These values are consistent with literature reports for pure MPI in water and biological-tissue analogues, where carrier densities on the order of $10^{14} - 10^{15} cm^{-3}$ are typically observed before AI becomes significant (Vogel et al., 2005; Stuart et al., 1996; Rethfeld et al., 2004). The temporal profiles themselves carry important physical signatures. In the pre-pulse wings ($t < -20fs$ for the 50-fs case, $t < -40fs$ for the 100-fs case), the laser intensity is too low to drive noticeable MPI, so $N_e(t)$ stays essentially at zero. As the pulse approaches its peak, the steep I^K dependence causes a rapid, exponential rise in $N_e(t)$, visible as the sharp up-turn in the semilogarithmic plot. The rise is slightly more gradual in the 100-fs case because the intensity ramp-up is slower, but the integrated area under the rate curve is significantly larger. After the pulse maximum, $I(t)$ decays symmetrically, the MPI rate drops sharply, and the curves flatten into a saturation plateau. The plateau value corresponds to the total density of seed electrons generated by MPI over the entire pulse. These MPI-generated seed populations form the initial condition for AI in realistic breakdown scenarios. In practice, once AI becomes active, the carrier density can grow by several orders of magnitude within only a few femtoseconds after the peak, but the efficiency of AI depends strongly on the seed density produced by MPI. Thus, differences in pulse duration, even at constant peak intensity, can have a decisive impact on the onset and progression of optical breakdown, as observed in (Stuart et al., 1996; Rethfeld et al., 2004; Vogel et al., 2005; Couairon and Mysyrowicz, 2007).

Following the MPI-only results in Fig. 1, Fig. 2 shows the simulated free electron density evolution when MPI, AI, and carrier recombination are all considered. In this regime, the MPI-generated seed electrons are rapidly multiplied through AI, where existing free carriers gain energy from the laser field via inverse Bremsstrahlung absorption and subsequently create secondary electron-hole pairs by impact ionization (Rethfeld et al., 2004; Stuart et al., 1996; Vogel et al., 2005). Since the AI rate is proportional to both the instantaneous laser intensity and the current carrier density, its contribution grows explosively once a sufficient seed population is present. This multiplicative process strongly depends on how long the optical field remains above the AI activation threshold, making the pulse duration a decisive parameter. In addition to these ionization channels, carrier recombination acts as a concurrent loss mechanism, whereby free electrons and holes annihilate over a characteristic recombination time. This process counteracts the increase of $N_e(t)$ and becomes particularly significant once the laser intensity has dropped below the AI threshold, limiting the persistence of high carrier densities after the pulse maximum. The balance between avalanche growth and recombination thus shapes not only the peak values but also the post-peak decay rate of $N_e(t)$.

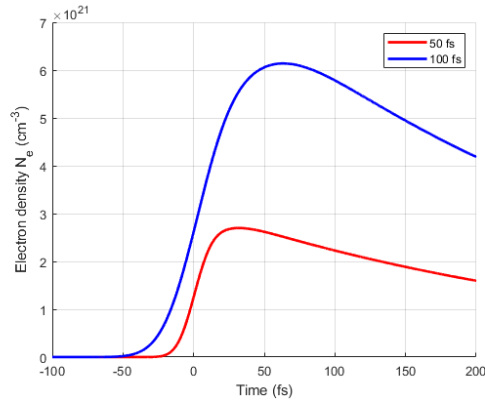


Figure 2. Temporal evolution of the free-electron density $N_e(t)$ in a skin-like medium for Gaussian laser pulses with durations of 50 fs (red) and 100 fs (blue) at the same peak intensity, $I_0 = 1 \times 10^{14} \text{W/cm}^2$ including MPI, AI and carrier recombination.

Both curves presented in Fig. 2 share the same initial phase: during the rising edge of the pulse, MPI seeds a small population of conduction-band electrons. As soon as this seed density becomes sufficient, AI sets in and drives a rapid increase in $N_e(t)$. The avalanche growth rate depends simultaneously on the field strength and the number of carriers already present, creating a positive feedback loop. The effect of pulse duration on this growth is evident. In the 50-fs case, the high-intensity window is narrow, and the AI phase is comparatively short-lived. The electron density rises steeply but saturates earlier, reaching a critical value of $N_{e,critical}^{50fs} \approx 2.698 \times 10^{21} \text{cm}^{-3}$ at $t \approx 32 \text{fs}$, after which recombination drives a gradual decay. For the 100-fs pulse, the broader envelope sustains strong AI for nearly twice as long. This extended interaction time allows the carrier density to grow well beyond the critical plasma density for 800 nm light, peaking at $N_{e,critical}^{100fs} \approx 6.139 \times 10^{21} \text{cm}^{-3}$ at $t \approx 63 \text{fs}$, before recombination begins to dominate the decay phase. The absolute values and timing of the peaks are physically consistent with ultrafast breakdown dynamics reported in the literature (e.g., Stuart et al., 1996; Rethfeld et al., 2004; Vogel et al., 2005). The later and higher peak in the longer pulse case reflects the fact that avalanche multiplication continues well into the trailing edge of the pulse, while the faster decay in the shorter pulse case highlights the stronger relative influence of recombination once AI ceases. These trends are quantitatively and qualitatively consistent with ultrafast breakdown dynamics observed in water and tissue analogues, where avalanche growth dominates the early evolution and recombination governs the relaxation phase (Stuart et al., 1996; Rethfeld et al., 2004; Vogel et al., 2005; Bulgakova & Rethfeld, 2010).

Following the carrier-density dynamics presented in Fig. 2, the simulated temporal profiles of $N_e(t)$ are coupled to the Drude model to calculate the time-resolved reflectivity change $\Delta R(t)$ for three probe wavelengths: 400 nm, 800 nm, and 1200 nm. This step provides a direct link between the ultrafast ionization physics and an experimentally accessible observable in femtosecond pump-probe reflectometry. Fig. 3 shows the resulting $\Delta R(t)$ traces for Gaussian pump pulses of 50 fs and 100 fs duration at the same peak intensity $I_0 = 1 \times 10^{14} \text{W/cm}^2$ as before. The spectral dependence of the probe response emerges naturally from the Drude formalism, where the transient plasma frequency depends on $N_e(t)$ and competes with the probe frequency in determining the complex refractive index and reflectivity (Vogel et al., 2005; García-Lechuga et al., 2017; Bonse et al., 2020; Inogamov et al., 2020).

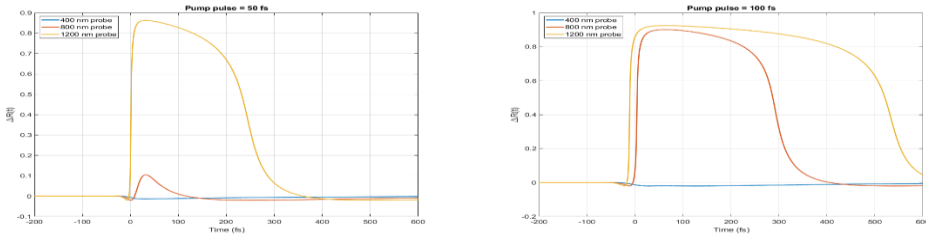


Figure 3. Simulated transient reflectivity change $\Delta R(t)$ for Gaussian pump pulses of 50 fs and 100 fs duration at $I_0 = 1 \times 10^{14} \text{ W/cm}^2$, probed at 400 nm (blue), 800 nm (red), and 1200 nm (yellow). The model includes MPI, AI, and carrier recombination.

For both pulse durations, the evolution of $\Delta R(t)$ reflects the steep onset of AI once the MPI-generated seed density surpasses the critical level required for efficient carrier multiplication. The probe wavelength strongly influences the magnitude of the transient reflectivity change. At 400 nm, the probe frequency is much higher than the transient plasma frequency throughout the interaction, so the refractive index perturbation is weak and $\Delta R(t)$ remains essentially zero in both cases. At 800 nm, the situation changes dramatically once $N_e(t)$ approaches the corresponding critical plasma density; here, the real part of the refractive index drops sharply, and $\Delta R(t)$ rises to pronounced peaks, reaching values close to unity for the 100-fs pulse. At 1200 nm, the high free-carrier densities reached during the excitation significantly enhance the refractive index contrast with the surrounding medium, producing strong positive reflectivity changes for both pulse durations. These wavelength-dependent trends are consistent with ultrafast optical breakdown studies in biological-tissue analogues (Stuart et al., 1996; Rethfeld et al., 2004; Golik et al., 2015; Bonse et al., 2020; Inogamov et al., 2020). The influence of pulse duration on $\Delta R(t)$ is equally evident. In the 50-fs case, the high-intensity portion of the pump envelope is short-lived, limiting the time available for avalanche multiplication. The reflectivity therefore rises steeply but reaches a lower maximum before recombination starts to dominate, and it decays more rapidly once the pump has passed. In contrast, the 100-fs pulse maintains its intensity above the avalanche threshold for nearly twice as long, allowing $N_e(t)$ to exceed the critical plasma density for both 800 nm and 1200 nm probes by a substantial margin. As a result, $\Delta R(t)$ not only reaches higher values but also remains elevated for a longer duration before the onset of recombination-driven decay. The temporal asymmetry in all curves reflects the delayed onset of avalanche growth relative to the pulse maximum and the persistence of recombination after the pump field has vanished. Such behaviour has been observed experimentally in femtosecond pump-probe studies of water, polymers, and skin-like phantoms (Golik et al., 2015; Mareev et al., 2024), confirming that the interplay of seeding, multiplication, and loss governs both the magnitude and the temporal profile of the transient reflectivity signal. It is important to state that this quantitative correspondence is further supported by the fact that the simulated peak reflectivity changes ($\Delta R \approx 0.8 - 0.9$ at $800 - 1200 \text{ nm}$) and corresponding critical plasma densities ($\sim 10^{21} \text{ cm}^{-3}$) closely match experimentally reported values presented in (Vogel et al., 2005; Golik et al., 2015; Mareev et al., 2024). These consistencies confirm that the chosen parameters and rate-equation model reproduce experimentally observed magnitudes and timescales of ultrafast reflectivity dynamics.

To further quantify the spectral dependence of the transient reflectivity response, we extracted the maximum values of $\Delta R(t)$ from the full pump-probe traces at each probe wavelength. This analysis enables a direct comparison between the short-pulse (50 fs) and long-pulse (100 fs) excitation regimes, highlighting how the interplay between MPI, AI, and recombination manifests across the near-infrared and visible spectrum.

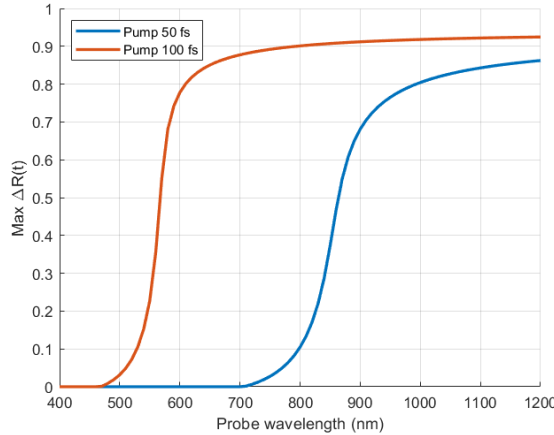


Figure 4. Maximum transient reflectivity change, $\Delta R(t)$, as a function of probe wavelength for 50 fs (blue) and 100 fs (orange) pump pulses at peak intensity ($I_0 = 1 \times 10^{14} \text{ W/cm}^2$) in a skin-like medium. Values correspond to the peak of the $\Delta R(t)$ traces shown in Fig. 3.

The spectral dependence of the peak reflectivity change exhibits a pronounced sigmoidal transition from near-zero response at shorter probe wavelengths to large positive values in the near-infrared. For the 50-fs pump pulse, this transition occurs gradually, with negligible $\Delta R(t)$ below ~ 750 nm and a steep increase between 800 nm and 1000 nm, eventually reaching saturation at ~ 0.85 around 1200 nm. In contrast, the 100-fs pulse produces a significantly earlier onset of the high- $\Delta R(t)$ regime, with a sharp rise already evident near 600-650 nm and saturation close to 0.9 for longer wavelengths. Physically, this shift reflects the higher free-carrier densities generated under the longer pulse excitation, which increase the refractive index contrast and modify the complex dielectric function more strongly across a broader spectral range (Rethfeld et al., 2004; Vogel et al., 2005; García-Lechuga et al., 2017; Inogamov et al., 2020). The earlier spectral onset for the 100-fs pulse is consistent with the fact that AI is sustained for a longer fraction of the pulse envelope, leading to higher peak carrier densities and thus stronger perturbations to the optical response. At the shortest probe wavelengths (< 600 nm), the reflectivity change remains minimal for both pulse durations because the Drude-like carrier contribution is small compared to the background response dominated by bound-electron absorption. In contrast, at longer wavelengths (> 800 nm), the free-carrier contribution becomes dominant, resulting in strong positive $\Delta R(t)$. For the 100-fs case, this regime extends well into the visible, while for the 50-fs case, it is confined primarily to the near-infrared. This difference clearly illustrates how pulse duration governs not only the temporal evolution of the transient optical signal but also its spectral distribution, a fact with direct implications for pump-probe measurements on biological tissue analogues.

Finally, examining how the maximum reflectivity changes maximum value of $\Delta R(t)$ varies with pulse duration τ_p offers direct insight into the onset and saturation of laser-induced plasma formation across different wavelengths. This analysis captures the combined effects of MPI, AI, and carrier recombination under identical peak intensities as in Figs. 1-4.

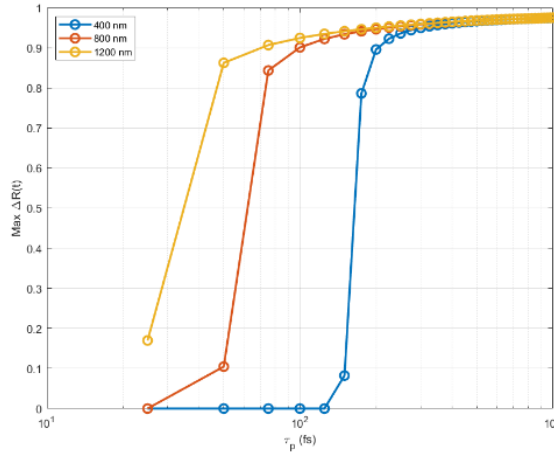


Figure 5. Maximum relative reflectivity changes $\Delta R(t)$ as a function of laser pulse duration τ_p for three wavelengths: 400 nm (blue), 800 nm (red), and 1200 nm (yellow). The peak intensity is kept constant across all cases.

The curves in Fig. 5 reveal a pronounced threshold-like behavior in maximal value $\Delta R(t)$ with respect to τ_p , reflecting the cumulative action of MPI and AI in generating a dense free-electron plasma. At 1200 nm, the threshold occurs for the shortest pulses among the three wavelengths. This is attributed to the relatively low MPI order and larger penetration depth at longer wavelengths, which facilitates faster carrier accumulation. At 800 nm, the threshold shifts to longer pulses, consistent with a higher MPI order and reduced penetration depth. For 400 nm, the threshold is reached only for significantly longer pulses, indicating that high-order MPI dominates the seeding process and requires extended exposure above the AI activation threshold for efficient plasma growth. In all cases presented in Fig. 5, once the threshold is surpassed, maximal value of $\Delta R(t)$ rapidly approaches unity, signifying near-complete plasma screening of the incident light. The saturation regime indicates that further increases in τ_p do not produce substantial additional reflectivity changes, as the electron density already exceeds the critical density for the given wavelength.

CONCLUSIONS

The numerical results presented in this study show that the spectral and temporal characteristics of the transient reflectivity in skin-like media are governed by the coupled dynamics of multiphoton seeding, avalanche multiplication, and carrier recombination. Longer pump pulses extend the temporal window above the AI threshold, enabling higher peak carrier densities that exceed the critical plasma density for a wider range of probe wavelengths. This enhanced free-carrier population increases the refractive index perturbation predicted by the Drude model, shifting the onset of strong positive ΔR toward shorter wavelengths and broadening the spectral domain of pronounced response. In contrast, shorter pulses limit avalanche growth, leading to lower $N_e(t)$ peaks, faster recombination-driven decay, and a delayed spectral onset of high reflectivity. These findings highlight the decisive role of pulse-duration-controlled carrier kinetics in shaping both the magnitude and spectral distribution of ultrafast optical signatures in tissue-like media.

Beyond their theoretical relevance, the results presented in this study also outline the physical limits within which femtosecond irradiation can be precisely controlled. The established

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correlation between excitation parameters and transient reflectivity thus provides a quantitative framework that may guide future applications in ultrafast laser diagnostics and selective photothermal interaction regimes.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper

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PROSTORNO-VREMENSKA ANALIZA DOSTUPNOSTI HELIKOPTERSKIH KAPACITETA ZA GAŠENJE ŠUMSKIH POŽARA NA TERITORIJI REPUBLIKE SRPSKE

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SAŽETAK

Ovaj rad predstavlja rezultate prostorno-vremenske analize dostupnosti helikopterskih kapaciteta Helikopterskog servisa Republike Srpske prilikom gašenja šumskih požara. Analiza je obuhvatila dvije postojeće baze helikoptera, smještene u Banjoj Luci i Trebinju i izvedena je korištenjem geografskih informacionih sistema (GIS). Korišteni su prostorni podaci o administrativnim granicama Republike Srpske, tehničke karakteristike helikoptera tipa A 119 opremljenih Bambi Bucket 2024 sistemom, kao i podaci o vegetaciji iz baze CORINE Land Cover. Generisane su vremenske zone dostupnosti od 10, 20, 30 i 40 minuta leta, uz dodatno vrijeme od jednog sata potrebnog za pripremu helikoptera i posade. Analiziran je procenat teritorije Republike Srpske unutar svake zone. Rezultati pokazuju da kombinovana pokrivenost dviju baza osigurava značajan obuhvat teritorije, ali i da postoje zone s ograničenom dostupnošću, posebno u kraćim vremenskim intervalima. Dobijeni nalazi mogu poslužiti kao osnova za optimizaciju rasporeda kapaciteta i unapređenje strategija zaštite šuma od požara.

KLjučne riječi: šumski požari, GIS analiza, helikopterske intervencije, vrijeme reakcije.

UVOD

Šumski požari predstavljaju jednu od najvećih prijetnji šumskim ekosistemima Republike Srpske, izazivajući ozbiljne ekološke, ekonomske i društvene posljedice. Brza i efikasna reakcija u početnoj fazi požara ključna je za smanjenje razmjera štete, pri čemu helikopterski kapaciteti imaju važnu ulogu u inicijalnom gašenju i podršci zemaljskim snagama (Ljubojević i Stanković, 2021). Efikasnost angažovanja helikoptera u gašenju požara zavisi od njihove prostorne raspoređenosti, vremena reakcije i dostupnosti kritičnim područjima. Prostorno-vremenska analiza omogućava kvantifikaciju pokrivenosti teritorije i identifikaciju zona koje su u optimalnim vremenskim okvirima dostupne postojećim kapacitetima. Helikopterski servis Republike Srpske za operacije gašenja požara koristi helikoptere tipa A 119, sa maksimalnom brzinom leta od 281 km/h, opremljene sistemom za prenos vode tipa Bambi Bucket 2024. Ova kombinacija omogućava brzo prebacivanje vatrogasnih resursa do požarišta i efikasno djelovanje u početnim fazama požara. Cilj ovog rada je da, korištenjem geografskih informacionih sistema (GIS) odnosno QGIS-a, izvrši prostorno-vremensku analizu dostupnosti helikopterskih kapaciteta za gašenje šumskih požara na teritoriji Republike Srpske.

METODOLOGIJA

Prostorni okvir istraživanja čine administrativne granice Republike Srpske. Lokacije baza helikopterskih kapaciteta preuzete su od Helikopterskog servisa Republike Srpske, pri čemu su identifikovane dvije operativne baze: Banja Luka i Trebinje. Helikopterski servis Republike Srpske koristi helikoptere tipa A 119, maksimalne brzine leta 281 km/h, opremljene protivpožarnim vedrom tipa Bambi Bucket 2024. Ova konfiguracija omogućava prenos i ispuštanje značajnih količina vode na požarištu, uz visoku manevrabilnost u zahtjevnim terenskim uslovima. Na osnovu tehničkih karakteristika helikoptera i informacija o operativnoj proceduri, definisana su četiri

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vremenska praga leta: 10, 20, 30 i 40 minuta. Na svaku od vremenskih zona dodat je fiksni interval od 1 sata pripreme posade i letjelice prije polijetanja.

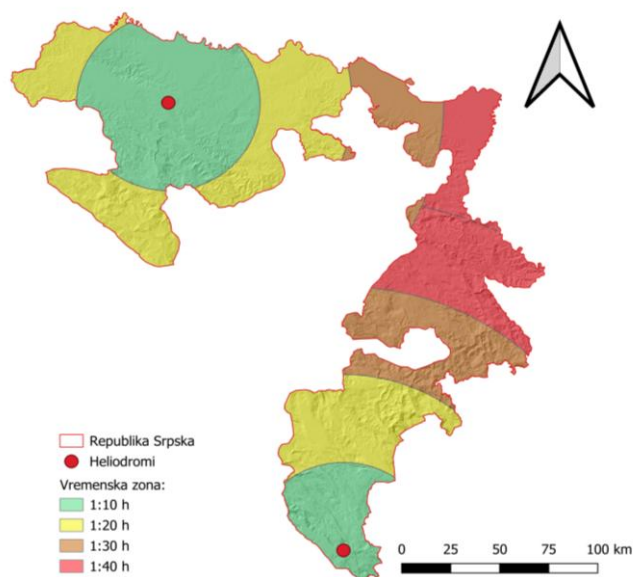
Analiza je provedena u tri koraka:

- Generisanje vremenskih zona dostupnosti iz baza Banja Luka i Trebinje korištenjem GIS alata (QGIS) i funkcija za prostornu analizu (buffer).
- Izračun procentualne pokrivenosti teritorije Republike Srpske za svaku zonu dostupnosti, odvojeno i kombinovano.
- Analiza pokrivenosti vegetacionih klasa relevantnih za šumske požare (CORINE 311, 312, 313, 321, 322, 323, 324) po vremenskim zonama (Ljubojević i Latinović, 2022).

Za vizuelni prikaz rezultata izrađene su dvije karte u QGIS-u: prva prikazuje lokacije heliodroma i pripadajuće buffer zone, dok druga prikazuje prostornu raspodjelu vegetacije po vremenskim zonama dostupnosti (Ljubojević i Latinović, 2022).

REZULTATI SA KVANTITATIVNOM ANALIZOM

Rezultati prostorne analize pokazali su značajne razlike u pokrivenosti teritorije između baza Banja Luka i Trebinje, uslovljene njihovim geografskim položajem. Banja Luka pokriva sjeverni i centralni dio teritorije, dok Trebinje pokriva južne i jugoistočne oblasti. U najkraćem vremenskom intervalu pokriven je ograničen dio teritorije, dok se povećanjem vremena leta do 40 minuta značajno proširuje zona obuhvata.



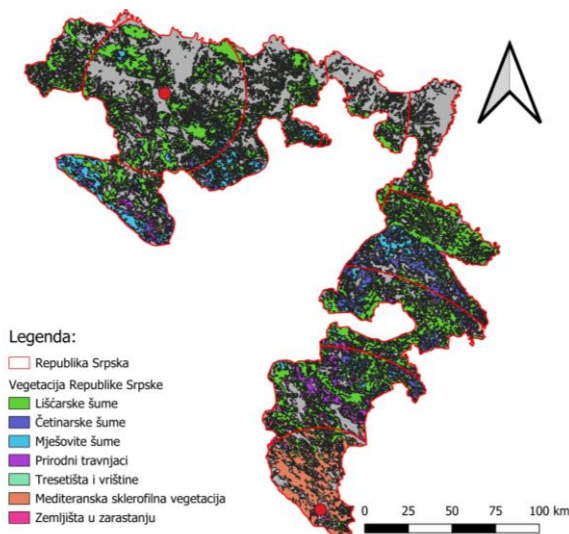
Slika 1: Lokacije heliodroma i vremenske zone.

Figure 1: Heliport locations and time zones.

Na slici 1 je prikaz lokacija heliodroma i pripadajućih vremenskih zona dostupnosti (buffer zone) za helikopterske kapacitete Helikopterskog servisa Republike Srpske. Buffer zone predstavljaju udaljenosti koje helikopter tipa A 119 može preći za 10, 20, 30 i 40 minuta leta, uz dodatno vrijeme od jednog sata potrebnog za pripremu posade i letjelice. Podaci su obrađeni u QGIS okruženju korištenjem vektorskih analiza i alata za generisanje zona dostupnosti. Ova karta prikazuje prostornu pokrivenost dviju postojećih baza (Banja Luka i Trebinje) i identifikuje područja koja ostaju izvan optimalnog vremenskog dosega.

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Analiza vegetacije ukazuje na to da su u dužim vremenskim intervalima obuhvaćene veće površine visokog požarnog rizika, dok su u kraćim intervalima značajne površine izvan zone dostupnosti. Karte generisane u QGIS-u jasno ilustruju prostornu distribuciju heliodroma, vremenskih zona leta i vegetacionih tipova unutar tih zona.



Slika 2: Prikaz tipova vegetacije i vremenskih zona.

Figure 2: Display of vegetation types and time zones.

Na Slici 2 prikazana je prostorna raspodjela vegetacionih tipova relevantnih za šumske požare unutar vremenskih zona dostupnosti iz baza Banja Luka i Trebinje. Korišteni su podaci iz CORINE Land Cover baze, pri čemu su izdvojene klase 311, 312, 313, 321, 322, 323 i 324, koje obuhvataju šumske i poluprirodne površine visokog požarnog rizika (Krčadinac, Ljubojević i Latinović, 2023). Karta prikazuje koliko su navedene vegetacione površine pokrivene helikopterskim kapacitetima u različitim vremenskim intervalima, čime se omogućava identifikacija kritičnih zona koje zahtijevaju posebnu pažnju u planiranju intervencija.

Analiza prostorno-vremenske dostupnosti pokazala je da raspored postojećih baza osigurava dobru pokrivenost većeg dijela teritorije. Tehničke karakteristike helikoptera A 119 omogućavaju brzo pokrivanje velikih udaljenosti, ali ukupna efikasnost zavisi i od vremenskih uslova, konfiguracije terena i dostupnosti izvora vode. Na osnovu rezultata, moguće je predložiti uspostavljanje privremenih operativnih punktova u područjima slabije dostupnosti, unapređenje procedura pripravnosti te kombinovanje sa bespilotnim letjelicama za detekciju i procjenu požara. Takođe, dalja istraživanja bi trebalo usmjeriti na uključivanje meteoroloških podataka, analizu istorijskih požara i modeliranje scenarija različitih operativnih konfiguracija.

Kvantitativna analiza prostorne dostupnosti helikopterskih kapaciteta izračunala je pokrivenost teritorije Republike Srpske u zavisnosti od vremena potrebnog da helikopter stigne do određene lokacije iz baza Banja Luka i Trebinje. Vrijeme reakcije podrazumijeva definisane zone leta od 10, 20, 30 i 40 minuta, uz dodatni sat potreban za pripremu posade i letjelice. Rezultati su prikazani u Tabeli 1, gdje su pored ukupne površine (izražene u hektarima) prikazani i procenti pokrivenosti u odnosu na ukupnu površinu Republike Srpske. Ovi podaci pokazuju razliku u prostornoj pokrivenosti između dvije baze, kao i kumulativni obuhvat kada se razmatraju zajedno.

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Tabela 1. Površina pokrivenosti teritorije po zonama leta .

Table 1. Area of coverage of the territory by flight zones.

Rd.br.	Heliodrom	Površina RS		Procentat
		Minuta	Površina [ha]	
1	Banja Luka	10	601108,44	24%
2	Banja Luka	20	581712,43	23%
3	Banja Luka	30	133633,54	5%
4	Banja Luka	40	129333,76	5%
5	Trebinje	10	209803,83	8%
6	Trebinje	20	298453,98	12%
7	Trebinje	30	266121,83	11%
8	Trebinje	40	294235,86	12%

Iz Tabele 1 se vidi da baza u Banjoj Luci ima dominantnu pokrivenost teritorije u iznosu od 57 %, dok baza u Trebinju obezbjeđuje pokrivenost od 43% teritorije.

Dodatno, izvršena je analiza pokrivenosti površina visokog požarnog rizika definisanih na osnovu CORINE Land Cover podataka, koji obuhvataju klase 311, 312, 313, 321, 322, 323 i 324. U Tabeli 2 prikazane su ukupne površine pod šumama i šumskim zemljištem (izražene u hektarima) po vremenskim zonama, kao i procenti pokrivenosti u odnosu na ukupnu površinu. Ova analiza pruža uvid u to koliki dio šumskih površina je u optimalnom vremenskom dometu helikopterskih kapaciteta, što je ključno za procjenu rizika i planiranje intervencija.

Tabela 2. Površina vegetacije po zonama i procenat u odnosu na teritoriju.

Table 2. Area of vegetation by zones and percentage in relation to the territory.

Rd.br.	Heliodrom	Vegetacija		Procentat:
		Zona	Površina [ha]	
1	Banja Luka	10	287634,96	19%
2	Banja Luka	20	339936,43	23%
3	Banja Luka	30	45433,36	3%
4	Banja Luka	40	37057,81	2%
5	Trebinje	10	157318,71	11%
6	Trebinje	20	217482,78	15%
7	Trebinje	30	194185,59	13%
8	Trebinje	40	209747,64	14%

Podaci iz Tabele 2 pokazuju da značajan procenat površina visokog požarnog rizika potpada pod vremenske zone leta od 30 i 40 minuta iz baze Trebinje. Ovi rezultati naglašavaju važnost optimizacije rasporeda resursa i potencijalnog uspostavljanja dodatnih operativnih punktova u područjima sa značajnim vegetacionim rizikom (Stojković, 2020).

Dobijeni rezultati potvrđuju da postojeće dvije baze osiguravaju značajnu pokrivenost teritorije, ali da u kritičnim intervalima reakcije (≤ 20 minuta) značajne površine visokog rizika ostaju izvan operativnog dometa. Ovo je posebno važno za područja koja su od baze Trebinje udaljena 30-40 minuta leta, što u praksi znači kašnjenje u početnoj fazi požara i povećanje vjerovatnoće nastanka većih ekoloških i ekonomskih šteta.

ZAKLJUČCI

Istraživanje jasno ukazuje na potrebu strateškog jačanja helikopterskih kapaciteta kroz uspostavljanje minimalno jedne dodatne operativne baze, koja bi omogućila ravnomjerniju prostornu distribuciju i značajno smanjenje kritičnih zona izvan optimalnog dometa. Takav raspored bi osigurao vremensku dostupnost od 20 minuta za veći dio teritorije Republike Srpske, što predstavlja ključni prag za efikasno suzbijanje šumskih požara u njihovoj inicijalnoj fazi. Povećanje prostorne pokrivenosti u ovom vremenskom okviru ne bi samo podiglo nivo operativne

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spremnosti, već bi i smanjilo rizik od nastanka velikih požara sa ozbiljnim ekološkim i ekonomskim posljedicama.

Dodatna baza bi omogućila i bolje povezivanje sa drugim segmentima sistema zaštite i spašavanja, poput zemaljskih vatrogasnih jedinica i službi civilne zaštite, čime bi se povećala ukupna sinergija i otpornost sistema. Posebno je važno naglasiti da optimalna prostorna raspoređenost baza direktno utiče na smanjenje vremena reakcije, što je jedan od presudnih faktora u procjeni uspješnosti intervencija.

Dalja istraživanja treba usmjeriti na kombinovanje ovog modela sa integracijom meteoroloških podataka, sezonskih obrazaca pojave požara i detaljne analize istorijskih događaja. Na taj način moguće je razviti scenarije koji bi simulirali različite operativne konfiguracije i omogućili donošenje strateških odluka zasnovanih na podacima. Takođe, uključivanje bespilotnih letjelica za detekciju i nadzor, kao i razvoj informacionih sistema za predikciju rizika, predstavljaju smjer u kojem je potrebno dodatno ulagati kako bi se postigao sveobuhvatan i održiv sistem zaštite šuma od požara.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper

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SPATIAL-TEMPORAL ANALYSIS OF HELICOPTER AVAILABILITY FOR WILDFIRE SUPPRESSION IN THE TERRITORY OF REPUBLIC OF SRPSKA

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ABSTRACT

The effectiveness of aerial interventions in wildfire suppression largely depends on the spatial distribution of operational capacities, response time, and logistical support on the ground. This study focuses on the territory of Republic of Srpska and analyzes the temporal accessibility of firefighting helicopters, considering flight performance, preparation time, and safe access to water sources. Using Geographic Information System (GIS) tools, temporal coverage zones were generated based on known helicopter base locations and technical characteristics. Additionally, the ground logistics of deploying mobile water reservoirs was examined through network analysis of the road infrastructure, aiming to model the actual time required to initiate an effective aerial intervention. By integrating aerial and ground response components, a comprehensive spatio-temporal model of resource accessibility was developed. The results can support strategic planning, optimization of firefighting resource allocation, and identification of areas with extended wildfire response times across the territory of Republic of Srpska.

Keywords: wildfire, GIS analysis, helicopter interventions, response time.

APPLICATION OF MODERN TECHNOLOGIES TO IMPROVE THE PROCUREMENT PROCESS: CASE STUDY OF THE COMPANY VENDOM

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ABSTRACT

In today's globalized and increasingly dynamic market, the importance of the procurement process, within the context of total cost management, is steadily growing. To ensure uninterrupted and continuous production operations in every modern enterprise, the procurement process should be regarded as one of the strategic functions. An efficient procurement process entails the application of best practice models and modern information and communication technologies across all stages: planning, ordering, execution, and control.

The subject of this paper is the enhancement of the procurement process through the application of modern information and communication technologies, primarily enterprise information systems, with the goal of business digitalization. The main benefits that digitalization brings to the procurement process include: strengthening the principles of transparency, efficiency, cost-effectiveness, healthy competition, and the procurement of high-quality materials.

This research is based on the real-world example of the company Vendom, which operates in the metal manufacturing industry. In its procurement process, Vendom uses *Pantheon*, an ERP (Enterprise Resource Planning) class business information system tailored for rapidly growing companies. The implementation of this system in Vendom's procurement process has led to significant improvements in business performance, reflected in: reduced procurement costs, optimized warehouse operations, more efficient raw material procurement, shortened delivery times for finished products, enhanced production quality, improved supplier relationships, better market positioning, increased customer base, and a greater volume of delivered goods, among other benefits.

Key words: improvement, procurement process, modern enterprise information system, company Vendom.

INTRODUCTION

The procurement process has been continuously changing over the last half-century in such a way that procurement is becoming an increasingly important factor in the functioning of a company. Supporting this, Ličina (2018) states that in the early 1980s, procurement costs accounted for about 40% of a company's expenses, whereas today they exceed 60%, with potential for further increase.

In today's global economy, procurement teams face increasing pressure to control costs and protect their companies from rising market risks. According to the World Bank report from 2023, the increase in tariffs raised procurement costs by an average of 10–15% (The World Bank, 2023), forcing companies to adopt strategic contract management and proactive supplier negotiations in order to mitigate growing financial risks.

Procurement involves significant costs for companies. Therefore, procurement units must continuously negotiate with suppliers and seek ways to reduce costs. This emphasizes the central role of procurement as a vital operational business process (Wirtz et al., 2015). Rising procurement costs may result from various factors such as inflation, supply chain disruptions, and increased demand. To manage these costs, companies may explore strategies such as negotiating better terms with suppliers, supplier consolidation, inventory optimization, and investing in technology for automation and data analysis.

Given the importance of procurement, which, as emphasized, has become a process of strategic significance, it is clear that modernization of the traditional procurement method was necessary. The application of modern technologies in the procurement process has proven to be an important step that enables companies to remain competitive in the market.

This paper consists of five sections. After the introductory considerations, the second part focuses on the procurement process in the company, and the concept and importance of the procurement function. The third part briefly presents ERP software as modern technologies whose application improves the procurement process, i.e., the digitalization of the procurement process. The fourth part presents a case study of the application of the *Pantheon* business information system in the company Vendom. The fifth part provides concluding considerations and the reference list used in this paper.

PROCUREMENT PROCESS IN THE COMPANY

The procurement process is one of the most important processes in every manufacturing company, as it ensures the availability of all necessary material resources. Improvement of the procurement process can contribute to reducing procurement costs through the acquisition of higher-quality raw materials, shorter delivery times, the production of higher-quality products, and improved business relationships with suppliers.

Companies that want to be competitive in the market under modern business conditions pay great attention to managing the procurement process, assigning it strategic importance. This means that quality and functional management of the procurement process significantly determines the amount of profit, thereby increasing the company's profit potential and, consequently, its overall growth and development potential.

Concept of Procurement

The procurement process is an extremely important part of every manufacturing company. Generally, procurement is the process of finding and acquiring materials, products, and/or services needed for the company's operations. The procurement function includes identifying needs and researching potential suppliers before negotiating contracts, making purchases, and managing supplier relationships.

The procurement process includes a series of subprocesses necessary for the procurement of materials, products, or services, and has several steps that must be followed, the most important being: ordering, receiving, and paying (Baily et al., 2008; Đukić Vujanović, 2021). The goal in managing this process is to reduce costs, shorten procurement times, and build quality business relationships with suppliers. "In a manufacturing company, procurement is a set of activities, measures, and tasks carried out for the purchase (procurement) of materials for reproduction, machines, devices, tools, and instruments to ensure an uninterrupted work process" (Vasiljević et al., 2024).

The concept of procurement can be viewed in both a narrow and a broad sense. Krpan, Varga, and Maršanić (2015) distinguish between these two views based on the types of tasks performed within the procurement process. There are two types of tasks: those performed almost daily and very frequently, directly related to procurement, categorized as operational tasks, and those performed only occasionally, falling under strategic tasks. Procurement in the narrow sense, as stated by Ferišak and Stihović (1989), includes specific operational and functional tasks such as: (1) receiving, examining, and consolidating procurement requests; (2) submitting requests to suppliers; (3) receiving and analyzing submitted offers; (4) selecting suppliers based on analysis;

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(5) ordering missing goods; (6) monitoring delivery flows and deadlines; (7) receiving and inspecting delivered goods and accompanying documentation; (8) lodging complaints to suppliers; (9) maintaining a procurement register; (10) controlling current inventory; (11) cooperating with other business systems; (12) reporting; and (13) selling surplus and waste materials.

On the other hand, procurement in the broad sense deals, in addition to the aforementioned, with many other operational, tactical, and strategic activities that occur over a period ranging from one to usually ten years. From the company's perspective, broad procurement includes not only material acquisition but also procurement of services, rights (licenses, leasing, rentals), energy, and work assets: equipment and capital goods (Žilbert, 2007; Preda, 2019). From the goal perspective, Krpan et al. (2015) define procurement as "the acquisition of materials or services of appropriate quality from an appropriate source, delivered in a timely manner to the appropriate location at an appropriate price."

The procurement function depends on a number of factors that can be divided into subjective and objective ones. Subjective factors usually refer to internal elements such as procurement policy, the organization of the procurement department, and the quality of the personnel responsible for the procurement function. On the other hand, objective (external) factors are considered to be market conditions, which can significantly influence the procurement function.

The procurement function should (Bloomberg et al., 2006):

- ensure continuous procurement of materials, raw materials, and services,
- minimize unnecessary investment and inventory-related losses,
- maintain or improve established quality standards,
- create and develop a quality supplier network,
- standardize procured raw materials and parts whenever possible,
- procure necessary raw materials of satisfactory quality at the lowest possible price,
- work to improve the company's competitiveness,
- operate in alignment with other parts of the company, and
- achieve procurement objectives with the lowest possible administrative costs.

Importance of the Procurement Process

Continuous supply ensures smooth operations for the company, cost control, and provides significant strategic advantages. The importance of the procurement function lies in its ability to optimize costs, improve quality, mitigate risks, and align with the company's goals.

The strategic importance of the procurement process can be viewed from several perspectives. First, cost reduction is extremely important, as a well-managed procurement process is a prerequisite for reducing expenses. Improved contracts with suppliers can lead to significant cost reductions and better profit margins, while optimization of the procurement process can help reduce waste and improve efficiency (Rimkūnienė, 2013). Well-organized business relationships with suppliers ensure continuous supply of quality materials, thereby eliminating delays and production issues.

Second, the impact of the procurement process on product quality and reliability is also important, as only the procurement of quality materials and products leads to the production of high-quality final products.

Third, the procurement process significantly influences risk mitigation in business, as it helps identify and manage risks throughout the supply chain, including supplier delivery issues, material quality problems, and market disruptions.

Fourth, procurement supports the achievement of company goals, as a strategic procurement plan aligned with company objectives leads to increased agility, resilience, and environmental sustainability (Rimkūnienė, 2013).

Fifth, the procurement function ensures that contracts with suppliers comply with current laws, safety protocols, and environmental regulations. Adhering to compliance requirements helps companies avoid fines, legal sanctions, and damage to reputation. Sixth, procurement is a key element in supply chains, ensuring a reliable and efficient flow of materials and products, meaning

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that efficient management of supplier relationships and monitoring of supply markets can optimize supply chain performance.

Finally, procurement can significantly influence a company's competitiveness, as optimized procurement processes can serve as a competitive advantage, enabling companies to offer higher quality products, faster delivery times, and lower prices.

MODERN TECHNOLOGIES AND THE PROCUREMENT PROCESS

The procurement process has significantly changed and evolved over the past twenty years. Today's procurement is largely a process based on business intelligence and information, as information management has proven to be a crucial factor in significantly reducing costs (Rejeb et al., 2018; Kalabanga et al., 2012).

New technological solutions have enabled faster, cheaper, and more transparent organization of procurement activities for both buyers and suppliers. Examples of modern information and communication (ICT) technologies have improved tender organization, ensuring the circulation of relevant information between buyers and suppliers in a way that reduces costs and time, while also contributing significantly to the company's flexibility in terms of procurement volume and mix (Rimkūnienė, 2013).

The modern evolution of the procurement process began with the digitalization of its activities, which led to the development of electronic procurement. The main advantage of electronic procurement is the increased efficiency of various tasks related to specific parts of the procurement process. Such an approach creates a new operational model that enables the creation of networks in real time, involving complete production processes and integrating ICT at various stages of business planning, including inbound procurement, outbound procurement, production, marketing, etc. (Rejeb et al., 2018; Đukanović et al., 2025; McMillan, 2025).

The creation of a new operational model is justified by the fact that the procurement process consists of a series of complex, interdependent activities that include need recognition, creation of technical specifications, supplier evaluation, and the final purchase decision, especially knowing that products and services procured within an organization can exceed 80% of its total costs. This reflects the need for companies to activate their procurement departments for innovation and contribution to the value chain (Day, 2002). All information, which forms the core of the procurement process and consists of communication (gathering information related to purchasing) and transactions (activities related to the purchasing process), must be analyzed, and decisions about procurement made accordingly (Osmonbekov & Johnston, 2018; Neely, 2004).

According to Hallikas et al. (2021), "procurement digitalization represents a path to electronic procurement and encompasses a set of practices and technologies that, through smart use of data, information and communication technologies, and automation, enhance the efficiency and effectiveness of existing processes and lead to the development of new procurement processes and activities." Procurement digitalization includes the use of technology to simplify and automate various phases of procurement, from need identification to payment for delivered goods to suppliers.

Digitalization of procurement results in a large amount of systematized information that forms the core of the procurement process and consists of communication (i.e., obtaining, finding, analyzing, and distributing information relevant to purchase decisions) and transactions, or activities directly related to the completion of the purchase itself (Rejeb et al., 2018).

The main goals of procurement digitalization are to improve efficiency, increase competitiveness, reduce procurement costs, and increase transparency in the procurement lifecycle. Digital procurement, often referred to as electronic procurement (e-procurement), involves the use of digital technologies and systems to simplify and automate various aspects of the procurement process, from purchasing and procurement to supplier management and contract lifecycle (Bogetić et al., 2021).

Digital procurement helps companies remain competitive in the market, with key benefits including: process standardization, acceleration of integrated procurement, cost limitation, and improved visibility and control (Paul et al., 2024; Nawaz, 2013).

ERP Software

In order to facilitate the management of key processes, one of which is certainly procurement, companies that aim to remain competitive in the market have implemented some form of ERP software into their operations. These are information systems for integrated resource planning. They are systems that “support process-oriented business management by enabling automation of information and business processes, while simultaneously integrating various services and departments of the company” (Belak & Ušljebka, 2014).

The main idea behind implementing this system is to achieve significant savings and increase efficiency in performing business processes, while also providing IT support for making important business decisions.

ERP software typically consists of multiple modules integrated with a single database that stores data from all parts of a given company. They allow for business automation, facilitate, accelerate, and connect processes within the company. There are several types of ERP systems, usually classified based on the implementation model into local, cloud-based, hybrid, and multi-cloud systems (Gessa et al., 2023). Each of these models offers different levels of control, scalability, and cost.

The most well-known ERP software includes: *Oracle NetSuite*, *SAP*, and *Microsoft Dynamics*, while the most commonly cited open-source solution is *Odoo Community* (Schwarz, 2025). In the territory of the former Yugoslavia, the most popular ERP software is *Pantheon*.

ERP Software *Pantheon*

ERP software *Pantheon* is a business information system that offers solutions for various business functions, including finance, accounting, production, wholesale, and others. The system is designed to help businesses of all sizes optimize their operations, improve efficiency, and make better decisions. This ERP system provides complete IT support for company operations regardless of the industry, integrating all business processes within the company. *Pantheon* supports all processes of a company, from product planning to final operational production, procurement, sales, and business analytics. It is a flexible software that can be easily adapted to user needs, provides opportunities for business optimization in the companies where it is applied, and can be used in companies of different sizes and industries.

The *Pantheon* business information system is the core product of the Slovenian company Datalab Tehnologije, founded in 1997, with the aim of developing an integrated business information system for small and medium-sized enterprises.

Some of the advantages of using ERP *Pantheon* are (Connect Software Solution, 2025):

- A unified database (regardless of the number of business units, all information flows into a central database, and since data is entered into the system only once, the possibility of errors is reduced and there is no data inconsistency),
- Integration of financial information in the case where a company has multiple business units and each unit has separate versions of financial reports,
- Integration of order information as *Pantheon* tracks customer/supplier orders from the moment the order is received, to delivery of goods and invoice issuance, i.e., throughout the entire procurement process,
- Standardization and acceleration of production processes, since *Pantheon* uses standard methods to automate individual steps in production processes, saving time, increasing productivity, and reducing unnecessary costs,
- User authorization possibilities so that access rights are defined in detail for each user, specifying what they can view, modify, and/or delete,
- Legal localization, meaning the system is prepared to operate in accordance with the laws of specific countries and features a user interface in the local language, with all notifications within the program translated into the user's language.

IMPROVEMENT OF THE PROCUREMENT PROCESS IN THE COMPANY VENDOM – CASE STUDY

This chapter presents the potential for improving the procurement process through the application of the *Pantheon* ERP software in the case of the company Vendom.

Basic Information About the Company Vendom

The company Vendom d.o.o. Laktasi has been operating since 2003 and is engaged in the production of metal products for both domestic and foreign markets, with a focus on international markets. It currently has about 200 employees and an annual revenue exceeding 10 million euros. The company's product range consists of various types of waste containers intended for the EU and South American markets, industrial and residential fences, smaller steel structures up to 100 tons, and complex structures for industrial needs up to 1000 tons. Vendom also produces platforms for underground and above-ground waste management systems, cranes for emptying containers, constructions, fences, steel molds, underground and above-ground containers, and various products made from all types of steel, produced according to customer requests or the company's engineering solutions (Vendom, 2025).

With such a product range, Vendom d.o.o. Laktasi is one of the largest exporters in the metal sector in Bosnia and Herzegovina. The most important competitive advantages of the company are: short delivery times, reliability, and quality. These competitive advantages, among other things, reflect the implementation of modern technologies in the procurement process. Such an approach has enabled Vendom's products to stand out in terms of design, innovation, and quality. The benefits of working with this company, from the clients' perspective, include responsiveness to specific customer requirements, product uniqueness, installation, servicing, and maintenance.

In connection with the subject of this paper, the following section will emphasize the use of the *Pantheon* software application in the procurement function.

Application of the *Pantheon* Software in Improving the Procurement Process in the Company Vendom

The company Vendom has modernized its operations by implementing the ERP *Pantheon* business information system, which is tailored for fast-growing companies. It is a business information system that enables control of all business processes in the company, which can be adapted to user needs and allows for business optimization. One of the modules of this business information system is intended for the procurement process. Therefore, to improve the procurement process in the company Vendom, *Pantheon*'s "Orders" module is used, which, among other things, enables monitoring of the entire procurement process, from requests and orders to supplier selection, delivery of goods, and storage. It is a comprehensive information system in which, at any time, one can view the status and flow of orders or received supplier pro forma invoices, as well as all changes to orders, offers, or pro forma invoices from customers.

Pantheon has improved and accelerated the procurement process in the company Vendom, and the process now occurs in six steps, most of which require IT support. The first step in procurement is carried out by the head of the procurement sector who, based on information received from the production sector and inventory levels, creates a procurement request. This information system in Vendom also allows for automatic creation of orders to suppliers based on received customer orders, which is an additional possibility for job automation, provided that the nature of the work allows for precise definition of supplier orders based on customer orders. This approach speeds up the ordering process but also implies skipping certain usual steps and carries a higher risk for the company, so despite time savings and prompt response to customer demands, it is rarely practiced.

After the first step and the request created by the procurement sector head, the request is electronically forwarded to the technical director for approval. Once approved, the request is forwarded to the procurement department. Based on the approved requests, the procurement department prepares an inquiry which is sent to suppliers. After receiving offers from suppliers, an

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analysis is conducted, and based on that analysis, a supplier is selected and the order is confirmed, with the delivery execution monitored. Finally, the warehouse manager and the person who submitted the procurement request are informed about the arrival of the goods, which will be stored in the designated location.

The home page of *Pantheon's* "Orders" module is shown in Figure 1 and opens after a purchase request has been approved (*Pantheon*, 2025).

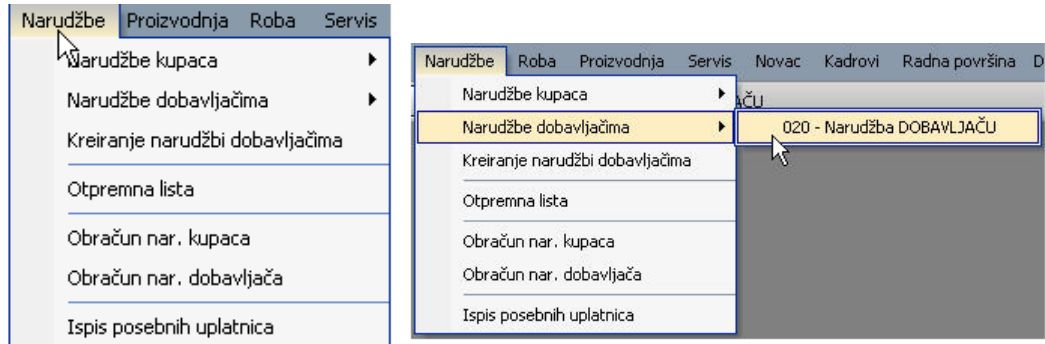


Figure 1. "Orders" Module

Upon approval of the procurement request and based on the previously created codebook, each individual order item is assigned a corresponding code, and the created request is sent to suppliers. This request may include a delivery deadline, which can be fixed or within a certain time range, along with many other criteria. **Figure 2** shows the form for creating supplier orders in the *Pantheon* program (*Pantheon*, 2025).

As already emphasized, the software allows for tracking all phases of the procurement process, from orders to delivery of goods, making it possible to better prepare the warehouse for receiving goods, as well as departments whose production depends on the orders. Furthermore, *Pantheon* in Vendom allows created orders to serve as the basis for invoice creation and goods issuance, as well as for creating work orders for production. It is also possible, in a simple way and based on customer or supplier orders, to create a receipt or dispatch invoice without re-entering data.

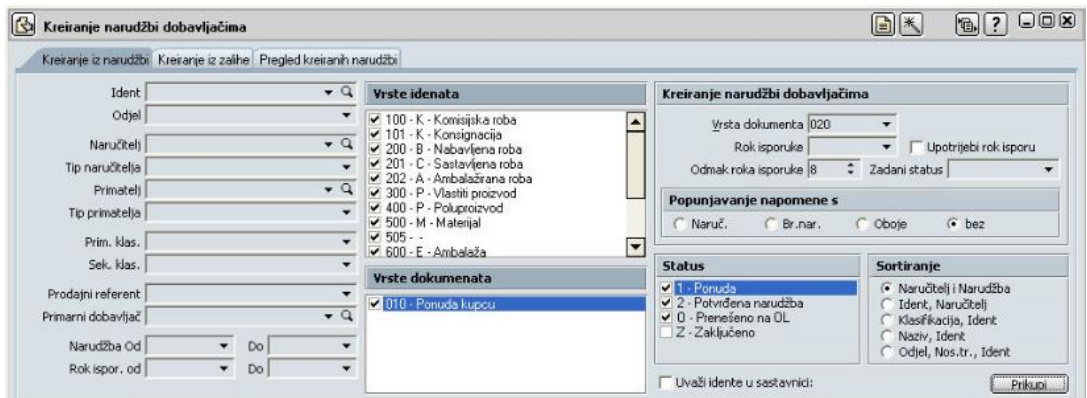


Figure 2. Creating Supplier Orders

When it comes to procurement cost allocation, all procured goods in the company Vendom are transferred (posted) to warehouses, so that costs can later be allocated by issuing goods based on approved requisitions, thereby defining the cost center.

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By applying the *Pantheon* business information system in the procurement process, Vendom has achieved significant benefits. Some of these include:

- A significant reduction in time from request creation to sending inquiries to suppliers (e.g., no more physically delivering requests for approval or retyping requests to send to multiple suppliers),
- Elimination of errors in ordering caused by poor retyping of requests,
- Full insight into the entire delivery flow,
- Significant reduction in paper and office supply usage, since communication is conducted exclusively electronically,
- Possibility of creating a comparative overview of submitted offers,
- All stakeholders in a given request can see at any time what stage their request is in,
- Easy access to the history of business relations with each supplier, including delivery delays, purchase price history, delivered goods quality, and more.

From the example in this case study, it can be concluded that the implementation of modern technologies in the procurement process in the company Vendom has led to significant improvements and acceleration of the procurement process. The main benefits are reflected in the reduction of procurement costs, warehouse optimization, procurement of higher-quality raw materials, reduction in delivery time of finished products, improved production quality, enhanced supplier relations, better market positioning, and an increase in both customer base and volume of delivered goods.

CONCLUSION

Procurement represents one of the most important processes in a manufacturing company, as it ensures the availability of all necessary material resources for the uninterrupted flow of operational production. The application of modern ICT in the procurement process makes managing this process faster, cheaper, and more transparent.

The application of the ERP *Pantheon* system in the procurement process of the company Vendom has resulted in significant benefits: the time from the creation of the procurement request to sending inquiries to suppliers has been shortened; the possibility of errors during order creation has been significantly reduced or even eliminated; the consumption of office supplies has decreased; supplier selection has improved in quality; the tracking of requests and goods has been enabled; and daily and online communication with suppliers and customers has been facilitated.

In addition, the implementation of this software in the company Vendom has led to reduced procurement costs, procurement of higher-quality raw materials, faster delivery times, improved product quality, and enhanced business relations with suppliers.

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